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VOL. 2 NO. 16 JULY, 1957

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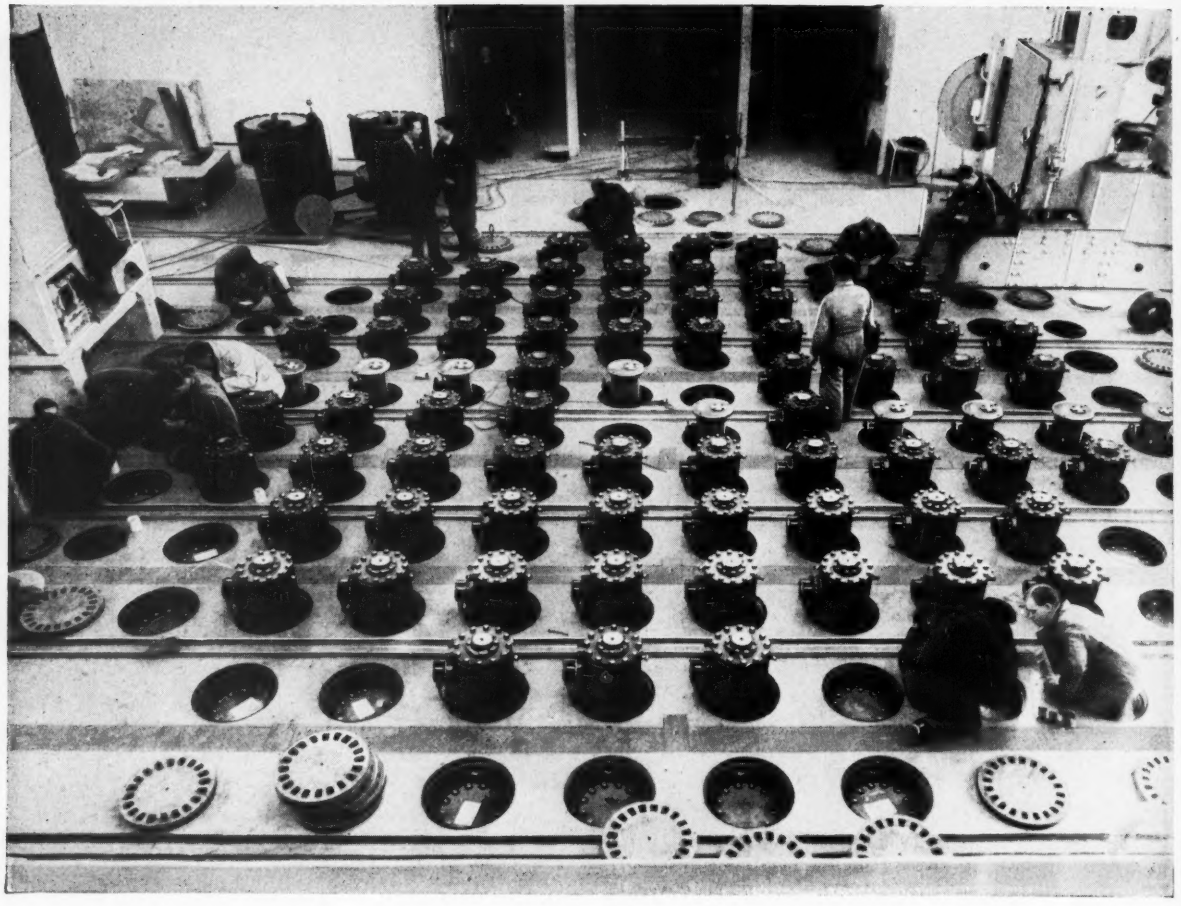

Controlling the reactors

AT CALDER 'A' Metropolitan-Vickers was responsible for the reactor control scheme and has supplied 120 actuating mechanisms and ancillary equipment. These mechanisms are for operating the combined control and shut-off rods and are arranged to provide a slow " out " and two faster " in " speeds. They will hold the rods in any required position and provide a controlled shut-off of the reactors independent of the electrical supply.

The pile cap during the installation of the control rod mechanisms at Calder Hall, Britain's first atomic power station. M-V is also responsible for the reactor control schemes at the Calder 'B' and Chapelcross power stations of the U.K.A.E.A., a further 360 actuating mechanisms being involved.

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NUCLEAR ENGINEERING VOL. 2 NO. 16 JULY, 1957

The U.K. and Euratom

A YEAR ago the United Kingdom was able to consider its position in relation to the hypothetical association of countries called Euratom with leisure. Before this link between the six nations of Western Europe—Belgium, France, Germany, Italy, Luxembourg and the Netherlands—for the development of the peaceful applications of atomic energy could be firmly established there were a number of detailed problems to be overcome, and there were many who felt that the nationalistic jealousies would be too strong for Euratom ever to become an effective force in nuclear development. The position has now been drastically changed. Ratification of the Euratom treaty by all six nations can be confidently expected within the next few weeks, and by the end of the year Euratom will be a live, working proposition.

Recommended Programme

That the association intends to tackle Europe's energy deficits in real earnest can be gauged from the recommendations of the three wise men who were called upon to report " on the amount of atomic energy which can be produced in the near future in the six countries, and the means to be employed for this purpose." Without atomic energy, the report maintains, energy imports would rise to intolerable heights, and whilst imports already amount to one-quarter of the total supply and represent an equivalent annual inflow of 100 million tons of coal, this figure would be doubled in ten years and could treble in twenty years. To stabilize the imports at the 1963 figure the report recommends the installation of 15,000 MW electrical capacity by 1967, that is something like twice the British programme of 6,000 MW by 1965.

The question, therefore, that must be answered in the near future is—can we afford to dissociate ourselves from this considerable enterprise? We have been warned that ultimately non-member states will not be able to compete in the European market on equal terms with the member states and although Western Europe will require to buy outside to begin with, it is her aim over the next few years to become largely self-sufficient even for raw material such as uranium.

The reason most commonly put forward in favour of our present policy concerns the lead in atomic energy that we have developed since the war. It is argued that the large British investment in atomic energy should be reserved for British exploitation and that the British taxpayer should not be placed in the position whereby he has effectively financed the early development of European electricity expansion. In the production of electricity from atomic energy our world-wide lead is undeniable (brought about because of our own needs), but what exactly are the advantages in maintaining a security barrier around it? How big is this lead and how much of this lead is specific knowledge and how much is experience, feel, know-how, whatever one calls it?

Assessment of Lead

It should be noted at once that in the opinion of the writers of the report experience on the Nautilus is equivalent to experience at Calder Hall and costs of electricity from a PWR in Europe would be much the same as from a Calder-type reactor, due to the higher investment charges. In terms of the time lead over the rest of Europe, we must remember that two years ago the consortia of companies that tendered to the C.E.A. were only just being initiated into the mysteries of the gas-cooled graphite moderated reactor and yet 18 months later they were able to submit designs that showed notable advances on Calder Hall. Considerable assistance and instruction was given by the U.K.A.E.A. over this period, of course, but the U.S.A. has already offered Europe equivalent assistance and we in turn have undertaken to assist no less in the training of technicians. This training aspect can be one of the most significant bottlenecks in the expansion programme, but with assistance from the U.S.A., the U.K. and Canada, apart from its own work in Universities and Atomic Energy Commissions, Europe should be able to muster a formidable array of skilled technicians in a few years' time.

Much more information is also available now than two years ago; many of the problems of power station design have been publicly aired and negotiations over the purchase of just one system would do much to provide information on the present state of technology. The purchase of only one of each system will further give operational experience comparable with any available

today and whilst there is a time lag the ability then to compare directly operational experience on systems designed in the U.K., the U.S.A. and Canada would allow a more rapid appraisal of various systems than is possible elsewhere. In the discussions between Euratom and the U.S.A., both parties have pointed out that the exchange of operational experience for basic information represents a "fair deal" and allows negotiations to proceed as between equals.

U.S.A. Our Competitor

This preparedness on the part of the U.S.A. to co-operate on an equal basis is perhaps the key to the whole situation. If the U.S.A. was inclined to adopt an aloof attitude to Euratom then perhaps we could afford to do the same, but we must be quite clear that the U.S.A. is our export competitor today and a competitor in deadly earnest, and she will be our only competitor until Europe has largely satisfied her own demands—and by then she will have unequalled experience in the nuclear field and will be able to compete on a bigger scale than we can hope to achieve.

We can of course for the time being simply follow the U.S.A.'s policy but, if it comes to a competition in generosity (or subsidy), there is little doubt as to who would win. We have neither comparable surplus capital nor surplus effort and we also have an immediate nuclear programme of our own to consider. The U.S.A. is in the happy position of being able to use Europe as a vast experimental field whilst we have neither the reserves nor the time. We should also have learnt to our cost how skilfully outside powers are able to play off the U.S.A. and the U.K. against each other.

From a long term point of view the issue is quite clear. Without our participation Europe will invest in nuclear power at a similar rate (demand for demand) to ourselves, to permit an entirely nuclear (electrical) installations programme by the late 60's. Industry will be given every encouragement to develop the capacity to meet this demand, with an eye to subsequently assisting in the developing of the under-developed countries. Co-operative research and development programmes, standardization of equipment, terminology, safety philosophy, insurance schemes, etc., will all make for efficient utilization of effort. Western Europe has a long tradition of high class development engineering, and for "one-off jobs" (nuclear power stations will never be "massed produced"), a record of achievement that is unsurpassed anywhere in the world. This country may claim a pre-eminence in original thinking and the U.S.A. in repetition projects, but Western Europe is capable of the very best in design—the faculty which in the long run can be of greatest significance. All this can create a situation where this country will have a most formidable opponent in the world export market with the closest market (Western Europe) amounting to some $2\frac{1}{2}$ to 3 times our internal market effectively closed to us.

Capacity and Technology

The immediate position must be examined not in relation to the relative advancement of British and Western European technology but rather of manufacturing capacity. Western Europe has manufacturing potential only 1.6 times that of this country in the atomic energy field, but more than double the internal electrical demand. Neglecting any advantages possessed by this country in terms of experience, equal apportioning of the constructional effort would result immediately in something like a 50% increase in orders for companies in the U.K. over and above the British programme. If this country does not integrate into Western Europe now, then European industry will expand appropriately with consequent increased facilities in allied fields. Capital is one major factor but there is little doubt that such capital would be made available, whilst U.S.A. help alone will do much to augment the necessary acquisition of machine tools in addition to providing educational help.

As an outsider, our prospect of immediate exports to Europe is circumscribed. Companies have already found that they need to change their ideas about selling whole power stations abroad and rest content with the idea of selling components requiring specialized and advanced techniques. This in view of stretched manufacturing resources on some fronts is probably no bad thing, and although certain items such as turbines could be sold almost off the shelf and therefore earn a good profit margin, traditionally British markets will still remain British and some markets not traditionally ours will change over if other reactor plant is ordered here. It could be reasoned that whilst Western Europe has no designs of her own it would be foolish to co-operate, otherwise the market would be limited indeed, but this is short-sighted, and ignores the scale of the overall programme and the relative manufacturing capacities. Co-operation increases the market, insularity limits it. It is short-sighted also to contemplate joining Euratom at some stage in the future, when development in Europe is on a par with our own, as we could not expect conditions of membership to be as favourable as today and we should have had no hand in formulating early policy. We should be in the position of junior applicant whereas today we could be senior partner.

Commonwealth No Barrier

Competing with individual countries with economies as strained as our own this country can be quietly confident, but when confronted with co-operative efforts and expanding economies then isolation could be disastrous. We are of course in Britain not just a single unit but a member of a Commonwealth but conditions here are very different from those in, say, Canada or Australia and our inseparable ties with these countries are no real barrier to our membership of Euratom. A reasonable formula is being worked out now that it has become apparent that we must associate with the common market project. The same can be done with Euratom—a precedent already existing with Belgium and the Congo.

If we hesitate over Euratom any longer we shall regret it; modesty is a traditionally British characteristic; let us not on such an important matter be led into the wrong policy through conceit.

Commentary

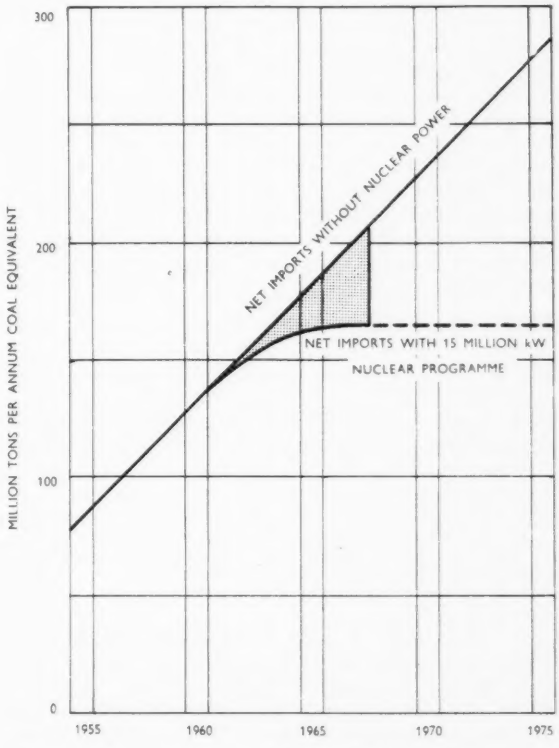
Payments of Royalties

The prolonged negotiations between Sir Edwin Plowden for the Atomic Energy Authority and Mr. Lewis Strauss for the American Atomic Energy Commission over the exchange of information on Calder Hall for similar information on the power unit of the Nautilus has brought into focus the whole question of whether companies should pay royalties to the United Kingdom Atomic Energy Authority for information received. One of the major problems has been that without some restrictions on the use of information supplied by Britain to the A.E.C., American companies would have free use of such information whereas their British counterparts would have to pay for it. Such a position is obviously unsatisfactory, particularly when the situation could arise that information supplied to the U.K.A.E.A. via the A.E.C. by American companies would then be sold to British industry by the U.K.A.E.A. The simple answer to this problem is of course to make the information free to all parties, and there are very strong reasons for believing that not only is this the simplest solution but also the right solution. The large British investment in atomic energy has been made because of this country's lack of other sources of power and because for our own sakes it is necessary to have available nuclear power at the earliest possible moment. Whatever the responsible body is that develops the system by which this power is obtained, and manufactures the stations which generate this power, the person that must ultimately pay is the taxpayer, whether this takes the direct form of taxation or the indirect form of paying more per kWh electricity consumed. It could be argued that the latter system whereby the electricity consumer carries the load is the fair one but the irrationalities that already exist in our taxation system are such as to make this a negligible consideration.

More important is the effect that payments of royalties have on the export prices of goods. It would be grossly unfair if power station components were sold to the electricity authorities in this country at a price higher than that charged abroad, whilst if royalties are paid on stations being exported then the Government is imposing on exports an indirect tax whilst the tendency in the United States is for the Government to subsidize such exports in order to encourage them. Subsidizing exports from this country would be unfair to other industries but taxations on such exports would not only be unfair to the nuclear engineering industry but most unwise at this stage.

The desire to make the U.K.A.E.A. pay its way no doubt springs from the highest motives but the A.E.A. is not and cannot be a commercial enterprise and any accounting system which tries to make it so is highly synthetic. Furthermore the issues are becoming rapidly obscured as the exchange of information is becoming progressively a two-way system whereby the A.E.A. is receiving valuable help from the development programmes that industry has initiated. The exchange rate is by no means equal as yet, but the fact that it exists at all means that cost accounting of it is impossible. There is also a great danger that a policy of self-sufficiency will encourage the A.E.A. to undertake projects which would be immediately commercially valuable rather than those projects which would, on a long term basis and from the country's overall development policy be the most worthwhile. In some cases, these may be the same, but certainly not in every case. Long term planning for example might decree the immediate inspection of a particular reactor system which had no immediate commercial application and although the ultimate motive for undertaking this project must be that it will be eventually commercially valuable, concentration on "making money" is almost certain to hamper imaginative thinking.

Energy Requirements of Euratom Countries



The influence of the nuclear installation programme suggested in the Euratom report.

PWR and Calder Hall Costs

There is still quite a diversity of opinion over the relative costs of generating electricity by the graphite moderated gas cooled reactor and by a pressurized water reactor. A report compiled by American Radiator-Standard Sanitary Corporation for the U.S.A.E.C. on this subject has now been released. The study compared the power costs of theoretical 90 MW plants of improved design (second generation) of the two systems, taking the U.S.A.E.C.—Duquesne Light Company's facility being built at Shippingport as its PWR standard. The report

concludes that, if built in the United States, a Calder Hall type would generate electricity at 17.9 mill/kWh against 19.6 mill/kWh for the pressurized water unit. With the lower construction costs and lower capital charges in Britain these figures should be modified to 8 mill/kWh and 13.1 mill/kWh respectively for plant built in this country. The figure for the gas cooled stations in this country is slightly higher than has been generally accepted as average for the C.E.A. stations now under construction corresponding as it does to a cost of approximately 0.73 d/kWh as against 0.66 d/kWh.

On the other hand the Euratom report suggests that costs of generation from both the Calder type and pressurized water type are roughly equal and are in the range 11 to 14 mill/kWh.

The actual figures and relative values will be a function of the investment charges of the country in which they are built, but it is significant to note that in the United States where investment charges are very high the American report still considers that the British reactor would be more economic.

It is surprising to note in the Euratom report that when discussing the relative costs the figures they quote are not considered to apply to the few reactors which will be brought into service before 1962 and which the report says are more prototype than commercial in character. This is a surprising statement in view of the highly competitive and commercial nature of the stations being built for the C.E.A. and the S.S.E.B. which will come into operation during 1960 and 1961. It is difficult to understand how such a misunderstanding could have crept in and we suggest that there is still a tendency in this country to talk about these stations as prototypes leaving the impression that they are still not a real commercial proposition.

Materials Testing Reactors

By the middle of next year three materials testing reactors will be operating in this country, DIDO and PLUTO at Harwell and DMTR at Dounreay. DIDO is largely concerned with straight irradiation of samples, the facilities in the reactor being small and numerous; PLUTO and DMTR on the other hand are provided with a relatively small number of large holes so that in-pile loop experiments can be performed. It is very doubtful, however, whether these three reactors will be sufficient to meet our needs. Already the programmes for them are mapped out for many months and there is a long waiting list of customers for the experimental facilities.

The speed of development of new systems will be largely governed by information concerning the behaviour of materials and fuel elements under irradiation conditions. When a low flux reactor is being designed, then testing in high flux reactors can yield equivalent long-term irradiation results in a relatively short period, but when the reactors for which the experiments are undertaken are to operate at neutron fluxes similar to those found in the experimental reactor then years of irradiation may be necessary. A reactor of the DIDO type costs in the region of £2 million and large-scale production of such reactors can obviously not be undertaken without mature consideration. But our facilities will not be sufficient to meet requirements, and the reactors that are now nearing completion whilst satisfying experimentors for a short time will have neither adequate fluxes nor adequate facilities to meet future requirements. Presumably however many testing reactors are available the experimentor will always maintain that just one more would make the difference, but we suggest that earnest consideration should be given immediately to the building of a much larger test reactor in which a greater high flux volume is provided and bigger experimental loops can be inserted. Of the three countries most advanced in the development of Atomic Energy—America, Canada and the United Kingdom, the U.K. will have the least facilities for in-pile work. Heat output is a reasonable measure of total facilities, and it is significant that a single industrial company in the U.S. (G.E.) is planning a 30MW reactor—equal to our total output—and NRU in Canada is rated at 200MW. It may be desirable to leave decisions for a short time until further experience has been gained upon DIDO and upon the installation of PLUTO and DMTR, but financial approval could be arranged and a site chosen.

Plutonium Prices

The U.S.A.E.C. has now announced the prices it is prepared to pay operators of U.S. power and research reactors for plutonium converted during operation. The prices the U.S.A.E.C. will pay between now and July 1, 1962 range from $30 to $45/g depending upon the Pu_{240} content; for the year July 1, 1962 a price of $30/g will be paid irrespective of grade. In view of the comments made in the U.S.A. over difficulties of burning plutonium and its somewhat doubtful value these prices are surprisingly high. Even the $30 figure is significantly higher than the £6/g originally quoted as a probable starting price for plutonium in this country but it is more than twice the figure that has recently been quoted as appropriate to the C.E.A. power stations.

In his recent paper to the W.P.C. (see page 295) Mr. J. A. Jukes (economic adviser to the U.K.A.E.A.) quoted a credit price for plutonium of 0.06 d/kWh corresponding to a metal price per gram of £4/6. The correspondence of these two figures is open to question and with high conversion factors, for the same credit price per kWh a metal price of around £3/g could be derived, i.e. $8.4/g, less than one third the future stabilized U.S. figure. If $30/g were credited for plutonium produced in the C.E.A. stations the cost per kWh would come down to below 0.5d and nuclear power would immediately be more economic than power from conventional stations. This all tends to confirm the suggestion that cost estimates in this country have been on the conservative side whilst U.S. criticisms of Calder calculations have been somewhat hasty. Certainly it shows the advantages of this country becoming a plutonium exporting area.

BICEP

A novel project is getting under way at Harwell. Dubbed BICEP it is designed to provide experimental facilities for the contracting Consortia for lattice measurements and detailed physics investigations of lattice arrangements and core fluxes. The British industrial co-operative exponential pile project will centre around a versatile exponential experiment in which with the minimum of effort the size of cooling channels, the lattice pitch and the details of the fuel elements can be changed. It is intended that the pile should serve the first four contracting companies and that programmes of work on it will be worked out by these four in collaboration, the experiments being supervised by Harwell. As an interim measure the project is clearly going to fulfil a need but some doubts must be expressed in the highly competitive atmosphere of power station design that sufficient co-operation can always be organized between the groups. BICEP should not be used as a lever to prevent companies acquiring sufficient uranium and graphite to enable them to build their own experiments if they feel the need.

Nuclear Energy in Sweden's Power Programme

by
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The overall energy position in Sweden and the current reactor projects are summarized. A review is given of the Government's estimates of expenditure for 1957 together with forecasts made by the officially appointed Atomic Energy Investigation Committee.

WHILST the energy requirements of Sweden have been increasing exponentially at the rate of approximately 5% per annum, for electrical consumption alone the figure is nearer 7%. Expressed in the equivalent weight of coal, yearly consumption per head of population for all purposes now amounts to 3.3 tons, corresponding to a total annual demand of 24×10^6 tons coal. Of this about half would be used in the production of electric power if it were assumed to be produced from conventional condensing power stations.

A somewhat pessimistic forecast predicts that whilst the total annual consumption of energy expressed in equivalent quantities of coal will amount to 36×10^6 tons in the year 1965 and 52×10^6 tons in 1975 the corresponding demand for electrical power will be 22×10^6 and 42×10^6 tons respectively, i.e., considerably more than half the total annual figures. It is interesting to note that the steep increase in the consumption of electricity is to a large extent attributed to an increase in domestic usage, from the present day 15% to almost 60% by 1975. The industrial demand for electrical power is expected to decrease over the same period from 60% to 39%.

Power Resources

Sweden's energy resources are in many ways peculiar to the country. Water power almost completely meets the demands for electricity and the home production of fossil fuels covers only a fraction of the remaining energy demand. Hydro-electric power with its high capital cost accounts for the base load production during the greater part of the year, whilst power from condensing stations with their high running costs supplies peak-load and reserve capacity. Hydro-electric power today costs approximately 1,000 crowns (£71) per kW in capital outlay; in addition, there are appreciable transmission costs since the hydro-electric power available is often found far from population and industrial centres.

Some contribution to power is also obtained from " back-pressure " plants. The main object of these is to produce process heat with electricity generated as a by-product by expanding the high-pressure steam in a turbine; the back-pressure is determined by the temperature level of the heat demand. Plants of this type are to be found in the paper and cellulose industries and in stations integrated into district heating schemes in the large cities. The amount of electric power available usually follows the demand for heat, which is highest in winter. This makes such power valuable since at this time of the year it is difficult to meet the power demands of the country with hydro-electric power alone.

Swedish power requirements other than electricity are met to a very large extent by the import of coal and oil from abroad. Certain native fuels exist, the most important of which is wood. Some peat and oil-shale is indigenous but coal is mined only in very small quantities. The relationship between the different energy sources expected over the next 20-year period according to official forecasts is shown in Fig. 1. The figures are expressed in million tons of coal equivalent.

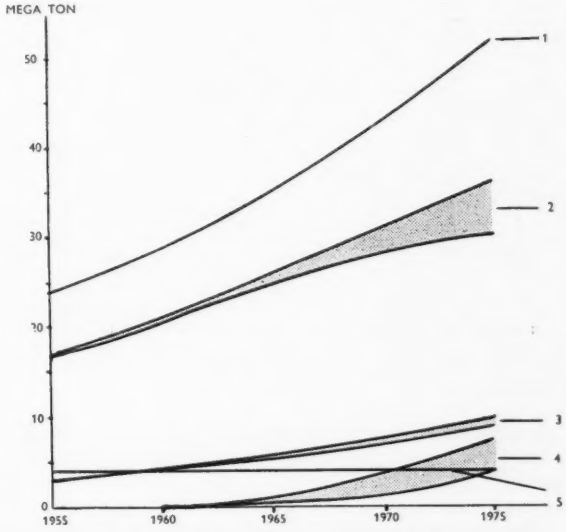

Fig. 1.—Analysis of Sweden's energy supply from various sources, in equivalent million tons of coal.
(1) Total energy consumption. (2) Imported fossil fuels. (3) Hydro-electric power. (4) Nuclear energy. (5) Conventional indigenous fuels.

Hydro-electric power is assessed according to its equivalent heat content. If evaluated according to the amount of coal which is required for condensing stations to produce the same quantity of electric power, the above values should be multiplied by a factor of 3-4.

Sweden's Projects

It is thought that atomic energy will in the future be used to satisfy the following demands:

1. Electricity for domestic and industrial purposes—condensing power stations.
2. Heating for large built-up areas, hospitals, industrial buildings, etc.—heating plants eventually combined with power production.
3. Heating for industrial processes—back-pressure plants or heating plants.
4. Mobile plants.

The position of hydro-electric power in the overall power supply has already been explained but further economic developments will be possible until the middle of the 1970s. After this time the increase in demand must be met by

atomic energy alone. The part of nuclear power within the overall system as far as one can judge will be as base-load supply. Only in the event of costs falling materially below those of hydro-electric power, will the position alter. Hydro-electric power will take over, to some extent, the part now played by steam power. Besides condensing

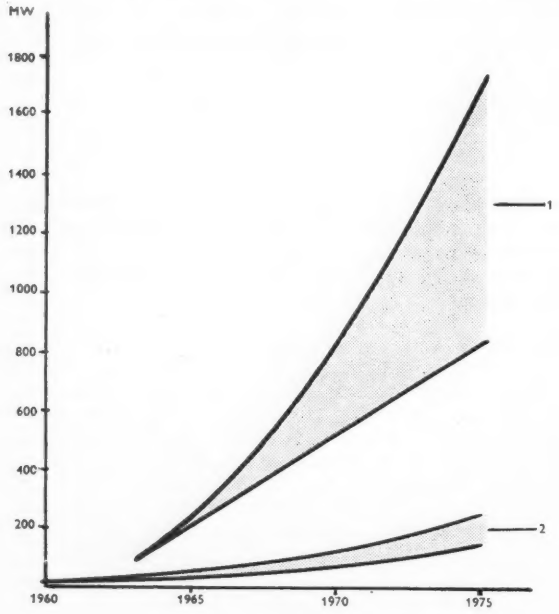

Fig. 2.—Estimated power to be produced from nuclear sources by (1) condensing power stations and (2) back-pressure stations. (The shaded areas show upper and lower limits of the forecasts.)

stations nuclear back-pressure stations will make a valuable contribution to electric supply (Fig. 2); this will be limited, however, since electric output is determined by the existing need for heat.

The first nuclear power station is planned to be ready in 1963 with an electrical output of approximately 100 MW. No construction details have been made public but it is highly probable that the main components will be natural uranium and heavy water. Furthermore, a nuclear power station of roughly double the size should be ready 3-4 years later; this has been mentioned as a minimum programme.

R-3 Project

Experience will, to a large extent, be obtained from a project at present under way at AB Atomenergi called the "R-3" Project; the plant is called "Ågestaverket" (Fig. 3). This is a back-pressure station under construction south of Stockholm and is scheduled to be in operation in 1960. The whole station will be taken over by the municipality.

With the reactor rated at 98 MW usable low-grade heat comprises 70 MW and the electric output about 15 MW with a possible full condensing power output of up to 25 MW. The low-grade heat is intended for heating houses at Farsta (situated about 4 km from the reactor station) and is supplied as hot water at about 100°C in an underground pipeline. The fuel will be natural uranium in the form of uranium oxide, with heavy water as moderator and coolant. The canning and pressure tube material will be made of Zircaloy, but an aluminium alloy might be substituted during the start-up period, the reactor working at reduced temperature and pressure and used for heating only, the output being approximately 70 MW.

The moderator maintained at atmospheric pressure and low temperature is contained in a tank of aluminium or steel (depending on the final form of the reflector) and is provided with a separate cooling system. It is insulated from the primary circuit by a helium blanket around the fuel element assemblies. Helium is also used as a covering gas. The reflector will probably be of graphite. It is estimated that a utilization of about 4,000 hours per year can be attained which for a back-pressure plant for heating purposes must be considered high. This is achieved by using oil-fired reserve boilers to take up the peak load during the winter and smaller load variations by means of a large hot-water accumulator.

The preliminary data for the reactor are shown in Table 1.

TABLE 1

Heat output	95 MW
Back-pressure heat	70 MW
Electrical output	15 MW
Heat output in primary circuit	86 MW
Coolant inlet temperature	220°C
Coolant outlet temperature	255°C
Pressure in fuel channels	63 at. a
Moderator mean temperature	35°C
Volume ratio D_2O/UO_2 in core	16
Core dimensions	3.0 m. dia. 3.0 m. high

Steam is generated in water-to-steam heat exchangers in four outer parallel primary coolant circuits. The total pumping power in the primary circuit is approximately 750 kW at 8 at. total pressure drop. Data for the H_2O side are shown in Table 2.

TABLE 2

Steam flow to turbine	145 tons/h
Steam pressure	23 at. a (saturated)
Temperature before the D_2O economizer	165°C
Back-pressure turbine output	15 MW
Heat distribution system:	
Temperature of inlet heating water	70°C
Temperature of outlet heating water	100°C
Heat supplied to consumers	70 MW

The design and construction work on the reactor is carried out by AB Atomenergi in co-operation with mainly Swedish industry which will deliver the greater part of the components going into the station.

Adam

Parallel with the R-3 project the State Power Board is working on a reactor project called "Adam" in co-operation with AB Atomenergi, who will be responsible for reactor construction. An agreement between AB Atomenergi and ASEA, Västeras, has been arranged, however, whereby AB Atomenergi sub-contracts to ASEA the main construction work on the reactor.

This reactor will also take advantage of natural features for containment and will be situated in the town of Vasteras about 100 km west of Stockholm. It will provide heat for industrial and domestic heating; the State Power Board has a contract to supply heat to the town of Västeras. The reactor, which is scheduled for operation in 1960, will be fuelled by natural uranium, probably in the form of oxide and moderated and cooled with heavy water. While aluminium will probably be selected for fuel cans and coolant channels it has been suggested that a steel pressure tank construction should be adopted, and moderator and coolant would not then be separate. In preliminary designs

TABLE 3

For primary circuit:	
Heat output	75 MW
Coolant outlet temperature	140°C
Tank pressure	12 at.
For the H_2O circuit:	
Inlet water temperature	70°C
Outlet water temperature	120°C

the heavy water passes in one direction only through fuel element assemblies which are suspended inside the pressure vessel without penetrating the vessel bottom. The reflector also is heavy water.

Other preliminary data are given in Table 3.

Although the two reactors (Project R-3 and Adam) described are closely allied the effect of detailed differences in construction will provide design data for future reactor projects. Several other communal and industrial projects are under review; there is interest in developing a reactor with a relatively low output (less than 75 MW) for heating schemes. In this connection, it is thought that light water reactors of low enrichment and of pressure-vessel design, would be particularly attractive. Data from such investigations have not been disclosed. It is planned that before 1965 at least one nuclear power station will be ready for operation. In the early stage AB Atomenergi called it " R-4 " but the State Power Board have named it " Eve." Further data on this reactor are scanty; it can be assumed that the reactor will be of 75-100 MW electrical output with natural uranium and heavy water as the main components as for the previous heating reactors. The question of gas or liquid coolant has so far been left open.

Research Projects

In order to obtain the technical background for a future reactor industry, Sweden must undertake an experimental and development programme. At present, basic research of this type is being carried out at universities and some privately aided institutions. Applied research has, up to the present, been carried on mainly by AB Atomenergi, which has had an experimental reactor " R-1," in operation in Stockholm since 1954. This reactor has natural uranium metal as fuel, heavy water as coolant and moderator, and aluminium as the canning material. It is a low-power and low-temperature reactor and is used as a radiation source for irradiating samples and for various physical experiments. Associated with it is a zero power arrangement, the so-called ZEBRA experiment.

Some details of the R-1 reactor are given in Table 4.

TABLE 4

Heat output	600 kW
Uranium charge	3 tons
Moderator weight	6 tons
Maximum thermal neutron flux	2×10^{13} n/cm²-sec
Core dimensions	1.7 m. dia. × 20 m. high
Average temperature of moderator and coolant	35°C

The moderator is contained in an aluminium tank surrounded by a graphite reflector and is circulated through an air cooler.

In order to gain experience mainly in the field of material technology for the construction of industrial reactors, AB Atomenergi intend to erect a high-flux material testing reactor " R-2 " at Studsvik about 100 km south of Stockholm on the Baltic coast. A plant for processing irradiated fuel from industrial reactors will also be built at this site and a zero energy reactor. A large part of Swedish atomic energy research will be concentrated at this place.

This high-flux materials testing reactor R-2 will be ready by 1958-59; it has been ordered from the American Car Foundries Inc., but Swedish firms will be sub-contractors for the project. It will be a light water reactor with enriched fuel in plates of uranium-aluminium alloy. The reactor core will be surrounded by a blanket of D_2O to increase the useful irradiation area without unnecessary absorbent material. The aluminium reactor tank is submerged in a basin. The change of fuel and other operations are carried out completely below water level. The reactor includes a number of separate channels for testing different types of fuel element. The enrichment will be at least 20% and the consumption of uranium about 40 g/day.

Some details of the reactor are given in Table 5.

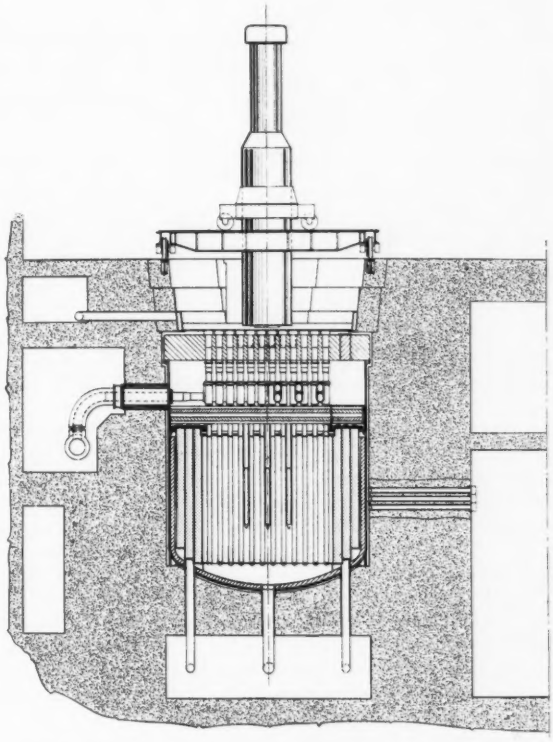

Fig. 3.—Sectional drawing of the R-3 reactor, showing header system, fuel elements and control rods, and main coolant and moderator pipelines. The shaded area inside the steel tank is a reflector of graphite canned in aluminium.

TABLE 5

Heat output	30 MW
Uranium quantity (20% U_{235})	35 kg
Core dimensions	0,8 × 0,8 × 0,6 m high
Max. thermal neutron flux	ca 10^{14} n/cm² sec
Primary coolant	H_2O of 50°C
Secondary coolant	H_2O of 10°C

Participation in the Swedish Atomic Energy Programme

AB Atomenergi which is four-sevenths state owned will be responsible for the near future development of different prototype reactors. This company will be solely responsible for fuel manufacture and for the processing of irradiated fuel and plutonium recovery. The company owns plants for the extraction of uranium from Swedish ore deposits, mainly from shale in central Sweden. There is also a plant for the production of uranium metal in Stockholm. These activities will be progressively increased. The state is responsible for the company's running costs but private industry is expected to maintain their interest; they contribute their share capital to a certain extent by providing manpower; the company thus also has the role of an educational establishment.

The purpose of the government in the programme will be of a controlling and legislative character. A government committee (Atomkommittén) was formed in 1945 to deal mainly with basic research. In 1956 a new advisory

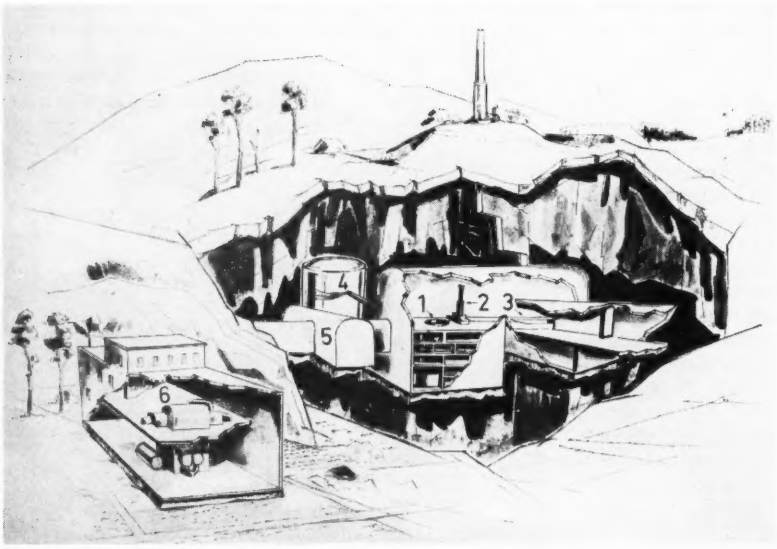

Fig. 4.—Artist's impression of the R-4 station.

(1) Reactor vessel with heat exchangers. (2) Charge-discharge machine. (3) Fuel element storage. (4) Expansion tank. (5) Tunnel connecting reactor and turbine halls, providing control room space. (6) Turbine hall.

committee was drawn up, directly responsible to the Crown, called the " Delegation for Questions of Atomic Energy." It will direct activities in the nuclear field and deal with questions of concessions and legislation. The work of the " Atomkommittén " will, in general, remain unchanged. As well as state and semi-governmental institutions it is naturally hoped that private Swedish industry will contribute to the development of this new source of energy. ASEA in Västeras and AB Atomenergi have, as already mentioned, agreed to co-operate on the Adam project. ASEA co-operates with North American Aviation Company and plans to start production of heavy water.

Companies manufacturing components for use in industrial reactor plants, such as pumps, heat exchangers, turbines, etc., have shown eagerness to adapt their products to meet the new demands which have arisen. As to production of materials, the Johnson Concern, through a special atomic energy department, among other things, has taken a special interest in the production of zirconium. Nohab (Bofors) can also be mentioned. The " Gustavsbergs Fabriker " in Stockholm have shown an interest in a smaller type of heating reactor with an output of less than 75 MW.

Regarding the ownership of reactors, it may be mentioned that in addition to the state, municipal authorities and private industries will erect and operate reactors with or without the production of electricity, and the existing private power companies will also own power reactors. To share in the capital and working costs for such projects, a number of the large power companies have united into a syndicate to form the "Atomkraftkonsortiet Krångede AB et Co," situated in Stockholm.

The mobile reactor projects have not been left out of the development programme; a working group has been formed —the " Institute for Shipbuilding Research " in Gothenburg. The institute includes members from the big shipyards and AB Atomenergi. A number of investigations have already been carried out, but no definite project has yet been indicated. The Swedish Navy has also shown interest in this work.

Conclusion

Because of the shortage of fossil fuels in Sweden, the country has depended to a great extent on imports of fuel from abroad. During crises, for example Suez or, even worse, the outbreak of war, the situation could be very difficult for the country's fuel consumers. With regard to supply of power the position is much more favourable because of the national water-power potentialities; these are, however, limited and by the 1970s the economic hydro-electric power will have been exploited. Although the uranium deposits in the country are considerable, they are unfortunately low-grade ores 0,2-0,3% uranium, and this naturally increases the price of the fuel. There are no thorium deposits. In order to be progressively less dependent on imported fuel it is intended to rely on the development of methods which will enable Sweden to produce fuel elements at a reasonable cost. AB Atomenergi mainly will be responsible for this work and will also initiate reactor developments, carry on research work and act in an advisory capacity.

The reactor programme has already started with heat and power/heat reactors, and the next stage will be power reactors. At the beginning the main components will be natural uranium and heavy water. The possibility of purchasing enriched material from abroad has also been investigated so as to give greater freedom in the construction of reactors during the initial period, while the country lacks plutonium from its own reactors.

Rights of ownership of industrial reactors for heat and power production will, in addition to the State, be given to both private companies and municipalities. The Crown has stated that question of concessions and laws will be settled with the help of a permanent atomic delegation. From the legal point of view these matters should not be greatly different from those of other countries in the reactor field. Proposals have been drawn up for consideration of the concession and security demands anticipated, but these will not be discussed here.

With the exploitation of the national uranium deposits and the adaptation of Swedish industry to reactor experience, Sweden has the possibility for a long period ahead to become more and more independent of fuel imports for its energy supplies. The possibility of an export industry in the reactor field can also be seen. The path to such an attractive goal is however long and laborious; nevertheless it is generally agreed to be worthwhile.

The Homogeneous Aqueous Reactor

Part II

by
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and D. NEWBY, B.Sc.(Eng.), A.M.I.Mech.E.
(*A.E.R.E. Harwell*)

In a previous article the homogeneous aqueous system was defined, and the relative merits of the system as a means of electrical power generation were examined. This article examines some of the problems of the reactor, and describes in greater detail some specific reactors which have been proposed.

AS stated in the first part of this article[10] the four major problems requiring development effort are:

(1) The technology of thoria slurries.
(2) The development of a suitable neutron-transparent, corrosion-resistant core vessel material (two zone system only).
(3) The development of reliable components.
(4) The development of remote maintenance techniques.

Minor problems include gas production and removal, and processing of the solution and slurries. As described here these problems are referred particularly to the two zone breeder reactor. Other types of homogeneous systems will have similar problems, but of different degree.

Technology of Thoria Slurries

This is a field where there is available, at the moment, little information of direct application. Concentrated slurries in excess of 1,000 g/l ThO_2 are needed in the blanket if a good breeding factor is to be obtained. Such a slurry of thoria in heavy water should retain the following characteristics under the conditions of temperature, radiation and fission obtaining in the reactor.

(1) It must be readily circulated without excessive pressure drop.
(2) It must not be severely corrosive or erosive.
(3) It must not plate out nor form hard cakes.
(4) It must be easily resuspended after settling.
(5) It must have suitable heat transfer properties.
(6) The material must be readily processed for removal of U233 and afterwards easily recovered from the processing cycle.

Thoria slurries can exist in either a flocculated or dispersed (deflocculated) state and it appears that the state can be changed by the addition of certain additives or by altering the temperature. It is important to know the state of the thoria slurry since it affects so many of the properties. A deflocculated slurry almost behaves as a normal Newtonian fluid whereas a flocculated slurry behaves as a Bingham plastic, i.e., it has a definite yield stress and its coefficient of rigidity is much higher than the viscosity of the deflocculated slurry. (This is illustrated in Fig. 4.) The disadvantage of a deflocculated slurry is that it settles to form hard cakes and is more difficult to resuspend after settling. Also the addition of corrosion products will be likely to flocculate the slurry. Such a change of state in the reactor would cause great changes in the pressure drop and at present the use of flocculated slurries is preferred. Thoria particles can be very hard and cause erosion at points where high rates of acceleration of the slurry occur, giving high shear and impact forces. The hardness of the thoria can depend on the method of preparation, and the rate of attack of the metal is affected by the presence of additives. Harder materials such as titanium suffer reduced erosion.

The formation of hard cakes in the system can present serious problems. It has been found to occur under certain conditions[11, 12] and can take several forms. One type is a hard film which forms on surfaces where high impact occurs. It contains some oxides of stainless steel but has not been found to interfere with the operation of slurry loops. Another type of cake occurs in such places as the

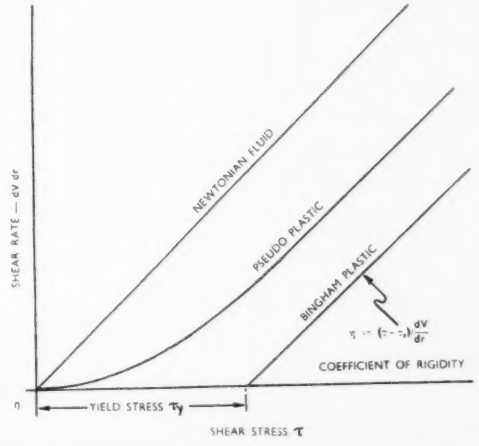


Fig. 4.—Variation of shear rate with stress for a Newtonian plastic and a non-Newtonian fluid.

interstices of the pump impeller in the form of hard lumps. It has been suggested that this type occurs when the sulphate content of the slurry rises above 10,000 p.p.m.[11] but it has occurred at other times and caused the failure of a pump.[12] Soft cakes are also produced occasionally.[12]

Settling of thoria in the blanket vessel and pipelines is also a problem. It has been shown by scanning pipes with γ-ray sources that settling of thoria can occur even when flow is considered to be turbulent.[13]

The many possible variables in the slurries include the method of preparation of the thoria, the particle size and particle size distribution and the presence of impurities. In addition there is the possibility of adding acids, bases or salts to the thoria to improve the properties whilst corrosion products and fission products produced in the reactor will also be present. These factors are interrelated,

e.g. while sulphates appear to reduce the corrosion-erosion attack they may enhance the caking problem. To cover such a wide range of variables under high pressure conditions would be an enormous task and as much information as possible is being derived from low pressure work on the sedimentation of slurries and from capillary viscometers.[14, 15] Confirmatory work must, however, be carried out at high pressure and temperature.

Corrosion Problems

The main corrosion problem in the two-zone system is that of the core container. Materials of low cross-section are required to act as "neutron-windows"; e.g. zirconium (hafnium-free), aluminium, magnesium and suitable alloys. Out-of-pile tests have shown Zircaloy 2 (a zirconium alloy containing approx. 1% tin, 0.1% iron, 0.05% nickel and 0.1% chromium) to be almost completely resistant to uranyl sulphate solution. Unfortunately, the corrosion rate becomes substantial when the metal is subjected to the combination of reactor radiations and fissioning uranyl sulphate solution e.g. at a fission power density of 4.2 kW/l in a solution of composition:

UO_2SO_4–0.04M, H_2SO_4–0.02M, $CuSO_4$–0.05M

At 280°C the corrosion rate of Zircaloy 2 is about 0.01 in./y.[16] This corrosion rate increases with increasing power density and temperature but is reduced by increased acidity.[16] The mechanism of the radiation effects on corrosion is by no means clear and much basic work is required on this difficult problem. The effect may be due to the action of β-radiation, γ-radiation, neutrons, fission fragments, chemical species produced by radiation, or by some combination of these effects on the oxide films. One theory of radiation-induced corrosion has been given by G. J. Jenks[17] but until the mechanism is clearer it will be difficult to select a suitable "neutron-window" material. A less satisfactory alternative would be to use a material of good mechanical and corrosion resistant properties but poor nuclear properties as a cladding. Another alternative which is the subject of a patent[18] consists of the use of a semiporous vessel through which clean D_2O is forced, thus preventing the solution from reaching the vessel walls. In application it is similar to transpiration cooling of turbine blades and aircraft surfaces.

The pressure vessel lining and the main circuit will be of stainless steel and the corrosion rates here will be lower and less important except that the large surface involved will produce daily a sizeable weight of corrosion products. The thin tubes of the heat exchanger represent a special problem, particularly since if stainless steel tubes are used, complete removal of chloride from the steam circuit would be needed. An alternative is to employ mild steel tubes clad in the bore with stainless steel.

Component Reliability

The development of reliable components for the reactor is another of the major problems. The chief mechanical items in the primary circuit are the main circulating pumps. These are required to operate under very arduous conditions, and they have to be completely leak-proof. The difficulties of maintenance require them to have exceptional reliability. The necessity for absolute leak tightness involves the use of canned pumps in which the rotor stator unit is integral with the pump bowl and impellor; thus the problem of shaft sealing is avoided. Shaft seals are always a possible source of leakage. The stator windings are protected from the corrosive action of the fluids by canning, and since suitable insulants are not yet available for the windings which are capable of withstanding the temperatures of operation (in combination, too, with the neutron and gamma flux which will be present) cooling of the unit is imperative. The bearings present major difficulties particularly where slurry pumping is considered, and it is usual to provide a subsidiary supply of clean heavy water to flush the bearings during operation. This supply can easily be obtained from the gas recombination unit. Such pumps have been developed, principally by Westinghouse in the U.S.A., and these have been manufactured in large sizes.

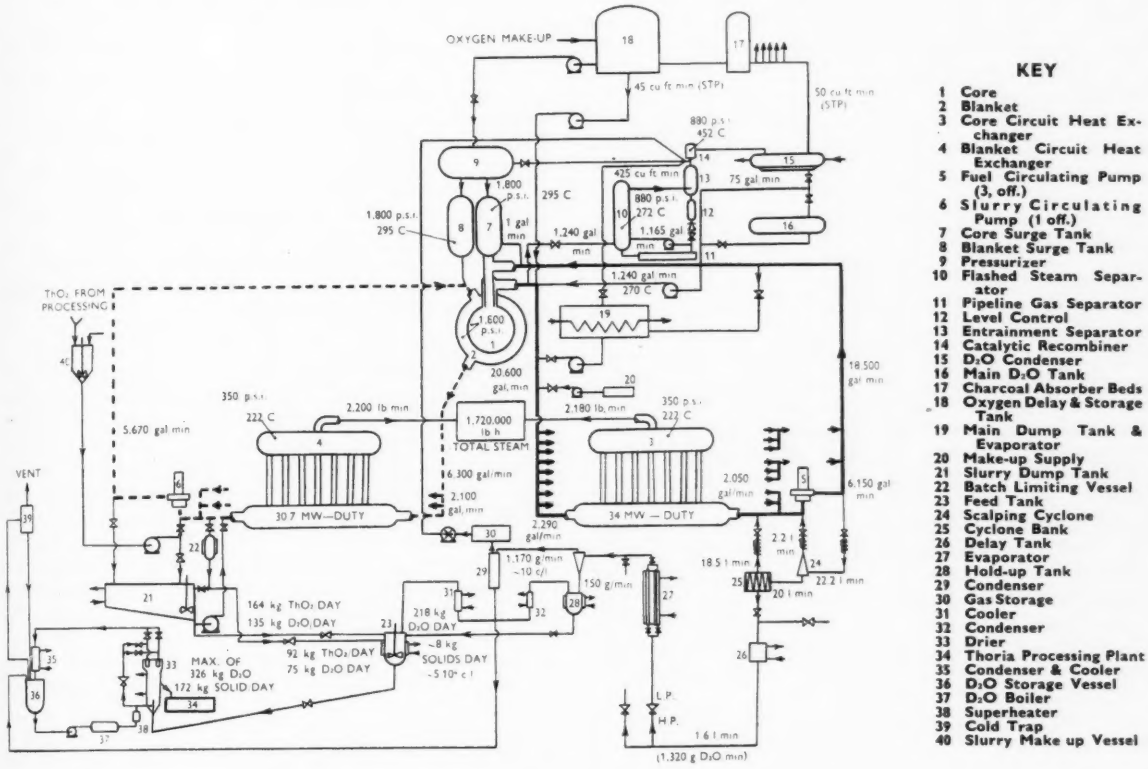
The other mechanical items in the circuit, such as make-up pumps, shut-off valves, let-down valves all require development, both for the core side of the reactor, where the corrosive conditions may be severe, particularly in regions of high velocity and, more important, for the blanket side, where the erosive nature of the slurry renders conventional designs undesirable. Again reliability is a factor of extreme importance if maintenance of the system is to be kept to a minimum.

It has been considered wise to use many small heat exchangers since maintenance in situ will probably be limited to removal and replacement. The main problems in heat exchanger design are those of achieving minimum hold up, minimum temperature drop, and avoiding corrosion/erosion at points of high velocity. The slurry heat exchanger too, must be such that slurry does not settle anywhere within the exchanger. Straight through tube and shell heat exchangers, with the primary fluid passing through the tubes are favoured since differential expansion problems are not expected to be severe. If failure of a tube occurs the steam side will become contaminated and arrangements must be made to ensure that the main steam stop valve, situated within the containment, will close automatically on detection of activity within the steam. Since the closing of this valve will require a finite time, a steam delay tank must be incorporated. Alternatively a secondary coolant circuit or double walled tubes in a single heat exchanger could be used, but both these produce further degradation of temperature of the resultant steam, and this is not at all desirable.

The main pressure vessel, which is intended to be spherical, about 10 ft i.d. has to withstand 2,000 p.s.i. operating pressure. The stress within the vessel walls will be increased by the gamma flux entering the vessel walls, and although this can be reduced somewhat by thermal shielding within the vessel, the resultant effect is to require a vessel with thicker walls than would normally be required. Since the inside of the vessel will be in contact with the fluids it should be lined with stainless steel, and the most favoured course to date is to use clad steel. The choice of material for the vessel wall is a difficult one as there are two opposing factors. On the one hand a high tensile steel is desired to reduce thickness and thus the stresses due to gamma heating. On the other hand it is known that one of the more undesirable characteristics of irradiation on materials is the reduction of notch ductility which occurs. The usual method of overcoming this is to use a steel which is very notch-tough and the effect of irradiation during the expected lifetime of the vessel is then only sufficient to reduce the notched ductility to a value which is still acceptable. Unfortunately high notch ductility is usually associated with low tensile strength and so a compromise has to be effected. The choice of an actual steel for use is still an open one, as data on the effects of irradiation under the operation conditions of this type of reactor are still rather meagre.

The core vessel which is contained within the pressure vessel presents few problems, once the material for its manufacture has been selected, apart from the connection to the pressure vessel, where problems of differential expansion may arise. The choice of material is a most vital one since the overall corrosion rate must be low enough to ensure that the vessel will have a life equal to the expected life of the reactor and freedom from local corrosion attack must be assured. It is difficult to conceive of a satisfactory method of replacing the core vessel alone, since this would require an opening in the main pressure vessel of at least 7 ft in diameter. The sealing of this closure would present serious difficulties under normal circumstances, and the additional requirements of 100% leak tightness, easy removal by remote means and the elimination of many gasket materials because of irradiation render the problem almost insoluble. An all-welded outer vessel is therefore considered desirable, and this implies that the core vessel must have an expected life equal to that of the remainder of the reactor.

Of the other components, such as dump tanks, condensers, recombination units, etc., little will be said. It is sufficient to stress that all present their own peculiar difficulties due to the environment under which they will be operating, the near impossibility of routine maintenance in the accepted sense of the term and therefore also the necessity for complete reliability.



KEY

1 Core
2 Blanket
3 Core Circuit Heat Exchanger
4 Blanket Circuit Heat Exchanger
5 Fuel Circulating Pump (3, off.)
6 Slurry Circulating Pump (1 off.)
7 Core Surge Tank
8 Blanket Surge Tank
9 Pressurizer
10 Flashed Steam Separator
11 Pipeline Gas Separator
12 Level Control
13 Entrainment Separator
14 Catalytic Recombiner
15 D_2O Condenser
16 Main D_2O Tank
17 Charcoal Absorber Beds
18 Oxygen Delay & Storage Tank
19 Main Dump Tank & Evaporator
20 Make-up Supply
21 Slurry Dump Tank
22 Batch Limiting Vessel
23 Feed Tank
24 Scalping Cyclone
25 Cyclone Bank
26 Delay Tank
27 Evaporator
28 Hold-up Tank
29 Condenser
30 Gas Storage
31 Cooler
32 Condenser
33 Drier
34 Thoria Processing Plant
35 Condenser & Cooler
36 D_2O Storage Vessel
37 D_2O Boiler
38 Superheater
39 Cold Trap
40 Slurry Make up Vessel

Fig. 5.—The flowsheet of the A.E.R.E. 2-zone breeder reactor design study (100 MW(E)).

Remote Maintenance

The maintenance of the reactor is a problem to which much thought must be given at the design stage, both of the individual components and the reactor itself. In the homogeneous system not only the reactor proper but the whole of the primary coolant circuits and the auxiliary circuits will be highly active, and normal routine maintenance will not be possible. Due to the plating out on surfaces of fission products, draining and flushing of the circuits will not reduce the activity level sufficiently to enable normal access to the system to be achieved. Maintenance will probably be limited to removal and replacement. Such removal could be done on a scheduled basis for components such as valves or pumps, but other components such as heat exchangers would only be replaced when failure occurred. Since the removal of these components can only be carried out remotely, the layout of the reactor system is governed by the maintenance system. There are two ways of remotely carrying out these operations, each leading to a basically different layout. In the first the reactor itself is shielded from the operators, who by means of remotely operated power tools, cranes, etc., disconnect and remove the offending item. In this case the most vulnerable items must be placed at the perimeter of the system, and also the perimeter must be as great as possible to afford a sufficiency of accessibility. The second way consists of shielding the operators from the reactor by enclosing them in a shielded cab (of a crane, for example) or gangway, from which they can perform similar operations. In this case the reactor layout can be more compact since the operator can have access to the interior as well as the periphery of the reactor plant.

In the two zone breeder system to be described later, the first approach has been adopted. The reactor proper is in

the centre of the layout with the heat exchange circuits radiating from it. This requires the containment to be in the form of a flat cheese, which is not an ideal shape for pressure vessel construction. One solution to this problem is the provision of a number of horizontal radial cylinders containing the heat removal circuits while the reactor would be contained in a vertical cylinder at the centre. Access would be obtained at the ends of the cylinders.

A problem which arises is the means of attaching the components to the pipework in order that they may be removed easily. There are two alternatives here; both have their attractions and the choice will be one of difficulty and compromise. The first is by means of flanged joints. Here, such joints have to fulfil two essential specifications. One is that they must be capable of easy assembly, and disassembly, while the second calls for absolute leak tightness. The joints used at O.R.N.L. for HRE were ring joints which had a leak detector system incorporated. Sealing was effected on two faces and the interspace, filled with clean D_2O, was pressurized and connected by small bore pipes to a central leak detection system. This method becomes cumbersome if many flanges are in use. On HRT delay in start-up has been caused by chloride contamination and subsequent stress corrosion cracking both of the leak detector lines and of the flanges.[19] An alternative method of component removal is to employ an all welded system and to use remote cutting, welding and inspection techniques for the pipe runs. The problems here are formidable but not insoluble, and the solution of them appears to be a worthwhile achievement as it would be applicable to other reactor systems.

When the components have been removed from the reactor they may either be stored pending thorough decontamination and repair, or they may be regarded as irreparable and disposed of.

Two other smaller problems arise from the use of a homogeneous system.

Gas Removal

In the primary core circuit various gases are formed during operation of the reactor and these must be removed from the system. In many ways this is an advantage since one of the gases formed is the fission product, Xe^{135}, which has a high value of neutron capture cross section. In heterogeneous systems it is not possible to remove this poison and thus the neutron economy of the reactor is seriously reduced. Large quantities of deuterium and oxygen are formed by dissociation of heavy water by energy deposition principally from fission fragments. Some degree of internal recombination of these can be achieved by the introduction of a suitable catalyst, such as copper in the form of $CuSO_4$. The effect of the catalyst is to reduce the over pressure of these gases at which recombination occurs.

Since copper is also a neutron poison (though not as severe in its effects as xenon) a balance has to be achieved between the following factors:—

(1) Gas Removal Rate.
(2) Neutron poisoning which can be tolerated (Xe+Cu).
(3) Over pressure of reactor.

Without the presence of a catalyst the production of dissociated gas takes place at a rate of 27 gmol/sec of O_2 and 54 gmol/sec of D_2 at a core power level of 320 MW. This is based on a G value (" the number of molecules of D_2 formed by dissociation/100 eV absorbed energy ") of 1.7.[20] The total cumulative fission yield of all the gaseous nuclides of Xe and Kr is only 1.2×10^{-5} gmol/sec, which would contribute a poison level of 6.3% if not removed.

There are two methods of gas removal at present favoured. The one used by O.R.N.L. in their homogeneous reactor test employs a centrifugal pipeline gas separator. After removal of entrained liquid D_2O vapour is added to dilute the gas mixture below the explosive limits, which is then reduced in pressure. Recombination using a platinized catalyst, and condensation of the D_2O precedes its reintroduction to the reactor. The remaining hard gases Xe and Kr, are then absorbed in charcoal beds. In the O.R.N.L. homogeneous reactor experiment the gas separation was effected centrifugally in the core. The Harwell design study has used a different system of gas separation whose principal advantage is the automatic production of a safe gas vapour mixture, thus eliminating any possibility of explosion at the point of separation. This employs a by-pass circuit operating at reduced pressure thus causing flash evaporation and is described later.

Solution Processing

Kilogram quantities of insoluble corrosion and fission products will be produced daily in a H.A.R. power reactor and efficient removal of this material is necessary for the best neutron economy. The size of the solid particles in the core solution to be expected under reactor conditions is not definitely known, but for simplicity, ease of control and minimum maintenance, small diameter hydraulic cyclones have been proposed for their separation from the core solution. When the size of particle to be separated has been confirmed by the operation of a reactor experiment or a high power in-pile loop, sufficient fundamental design data are available for a hydraulic cyclone to be designed to provide the necessary separation.[21]

The soluble neutron poison level in the core solution is controlled by the rate of withdrawal of solution from the core circuit. The level of U^{233} in the thoria blanket is maintained by bleeding off a stream of slurry for processing. Economic considerations entail the maximum recovery of heavy water from both the blanket slurry and the core solution prior to their processing in light water systems and detailed methods of achieving this performance have to be worked out.

Solvent extraction methods following conventional lines are proposed for the processing of both the core and blanket solids but at present there is not a great deal of knowledge on the behaviour of Pa^{233} (the precursor of U^{233}) in such systems.

A Typical Two-zone System

A design study of a two-zone breeder reactor to produce 100 MW(E) has been made at Harwell.[22] The system chosen uses a core solution of uranyl sulphate and a slurry blanket of thoria in heavy water, the flowsheet being given in Fig. 5. The specification of the system is given in Table 3 but it must be realized that the selection of some of the parameters was made on a somewhat arbitrary basis, e.g., the distribution of the power output 300/100 between core/blanket.

Power Removal Circuits. The uranyl sulphate solution leaving the core vessel at 290°C. passes through nine identical evaporators in parallel, where it is cooled to 240°C. Each bank of three straight-through, single-pass, natural circulation evaporators is coupled to a canned rotor

Fig. 6.—Diagrammatic layout of the A.E.R.E. 2-zone breeder reactor study (100 MW(E)).

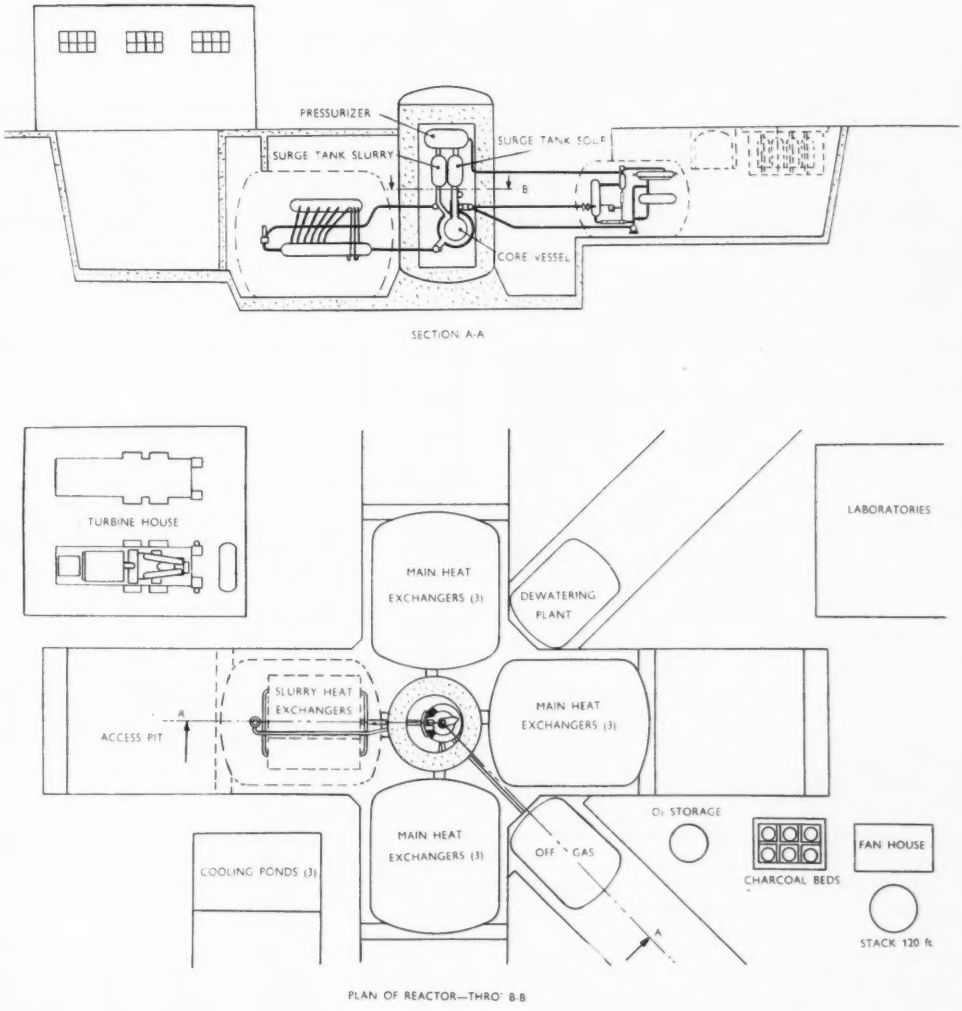


TABLE 3

Brief Specification of 2 Zone Breeder Reactor Operating on Th232–U233 Cycle (AERE Design Study)

Core fluid: 1 $gU_{233}/_l$ as UO_2SO_4 dissolved in D_2O
Blanket fluid: 1000 $gThO_2/_l$ slurry with D_2O

	Core system	Blanket system	Entire system
Diameter, feet	7	11	—
Operating pressure, p.s.i.	1 800	1 800	—
Operating temperatures, °C.	240–290	240–290	—
Mean flux in reactor zone, n/cm^2–sec	10^{15}	5×10^{13}	—
Circulating rate (mean), i.g.p.m.	20 000	6 000	—
Power density in reactor zone (mean), kW/litre	60	6	—
Thermal load, MW	300	100	400
Electrical output (net), MW	—	—	96
Material inventories (including processing), kg			
U_{233}	40	50	90
Pa_{233}	—	20	20
ThO_2	—	24 000	24 000
D_2O	17 000	20 000	37 000

centrifugal pump which returns the solution to the core vessel. The design duty of each evaporator is 35 MW of heat with saturated steam generation at 350 p.s.i. Three 30 MW evaporators remove the heat from the circulating slurry. The single-pressure saturated steam cycle with bled-steam feed heating has an interstage moisture separator operating at about 30 p.s.i.a. to reduce the wetness of the steam in the l.p. stages. An overall thermal efficiency of 25% is envisaged.

Gas Handling Circuit. Complete suppression by copper catalyst of the radiation decomposition of the water into D_2 and O_2 is not employed since a purging gas is required to sweep out the Xe^{135} neutron poison. The gas handling circuit of Fig. 5 is designed to maintain the poison fraction in the core circuit at 0.01. The copper poison fraction is also 0.01.

A small fraction of the main core circulation is by-passed through a pressure reducing unit where its pressure is lowered from the system pressure of 1,800 to 880 p.s.i. Partial evaporation occurs and most of the Xe^{135} together with the deuterium and oxygen in the solution enter the gas phase. The resulting gas/vapour mixture contains less than

5% D_2+O_2 and this is considered to be well below the explosive limit. After separation of the gas phase from the sulphate solution the D_2O is reformed from the deuterium and oxygen in a catalytic recombiner and condensed. The resulting D_2O is mixed with the separated sulphate solution and pumped back to the main circuit. The residual gas stream, after removal of the D_2O, flows through one of a series of charcoal absorption beds where the Xe^{135} is removed, the excess oxygen returning to the main circuit. In such a circuit the deuterium is removed at a rate of 7 gmol/sec, i.e., 85% of the deuterium is recombined internally.

It has been proposed that the dissociated gases could be used for super-heating the steam produced in the reactor. This is considered undesirable since the gas removal circuit would be unduly large (it would have to handle nearly 8 times the quantity of D_2 flowing in the above circuit) and the recombination at the elevated temperatures necessary would present explosive hazards. Since also, the maximum amount of heat that could thus be produced would be only about 4% of the core heat, the degree of superheating achieved would be insufficient to increase the thermal efficiency of the steam cycle significantly.

Pressurizing. A common pressurizing tank maintains the core and blanket circuits at the same operating pressure. There is provision for purging this tank to the gas handling system to prevent build up of decomposition gases and Xe^{135}.

Processing Circuits. Neutron poisons in the form of corrosion and fission products are produced in the core solution and good neutron economy requires their removal. The bulk of the corrosion product will exist in suspension and can be removed by a solid-liquid separation technique. Most of the non-gaseous fission products will remain in solution and can only be separated by chemical processing techniques. As shown in Fig. 5 processing rates are selected to control the poison fraction due to corrosion and fission products at 0.03.

The solid products are removed by a small diameter hydraulic cyclone, suitably protected against large size solids by a scalping cyclone, the whole cyclone circuit operating across a main circuit pump. The level of soluble poisons is maintained by feeding the underflow stream from the cyclone circuit to a processing circuit. Prior to this processing in a light water circuit, complete removal of D_2O is required. A climbing film evaporator performs the major D_2O removal. As it is proposed that the core material be processed together with the thoria, the evaporator concentrate and the thoria take-off can be batched and dried together. A fluidized bed drier using superheated heavy steam as a fluidizing medium is suggested for this duty, the dry thoria and core solids being removed and fed to the external processing circuit.

Conventional solvent extraction methods[23] are used in the processing plant to separate the U^{233}, Pa^{233}, thorium and fission products. The dry material, including that from the core, is dissolved in nitric acid containing ammonium fluoride and the Pa^{233} is adsorbed on manganese dioxide. The U^{233} is first extracted from the nitric-fluoride solution by 5% tributyl phosphate in diluent and the thorium removed later by 40% T.B.P. The Pa^{233} decays to U^{233} and after six months this can be redissolved in acid and fed to the solvent extraction cycle. The U^{233} nitrate recovered from the solvent is dried, calcined to uranium trioxide and converted to uranyl sulphate with deuterated sulphuric acid. The recovered thorium nitrate is converted to oxalate, dried and calcined to thorium dioxide.

Layout. Complete containment is required of all high pressure equipment containing active solutions or slurries. In the layout adopted (Fig. 6) the containment comprises a number of interconnected cylindrical containers buried several feet below ground level with access to the ends of the cylinders. The central vertical cylinder contains the reactor vessel, the surge tanks for the solution and slurry circuits, the pressurizer and the distribution manifolds for the two circuits. The outer vessel, designed to withstand the full failure pressure, is lined with a blast shield of high density concrete. Four radially located horizontal cylinders contain the active solution and slurry circuits. The main solution flow separates into three identical circuits of three evaporators plus one pump, each housed in its own container. The fourth container holds the blanket circuit. These four horizontal cylinders also contain the dump tanks, dumping being effected directly from the individual external circuits. The evaporators are mounted side by side on rails running the length of the container the pump being mounted integrally at the end remote from the main core vessel container. A concrete-lined cutting leads to the pump end of the container, ending in a removable concrete slab shield. Provision is made for partial or complete removal of the shield, and access ports, through which maintenance work can be performed remotely on the main pump and evaporators, are provided in the end of the cylinder. Two smaller horizontal cylinders house the gas handling circuit and the integral core processing circuit. From the latter a dewatered product is removed to the main processing plant.

The seven main containers are connected by large ducts through which pass the inter-connecting pipes. Steam passes from the evaporators through a delay tank to the saturated steam turbines. A small oil-fired boiler, adjacent to the turbine house, provides the start-up heat for bringing the reactor up to operating temperature.

Material Utilization. Table 3 shows that approximately 1.1 kg of U^{233} will be required per MW(E), including the hold up in the external processing circuits, with a D_2O requirement of about 0.4 tonne/MW(E).

Superheating. The H.A.R. produces only dry saturated steam, and the question of a separate oil-fired superheater is often raised. This has been investigated recently at Harwell, and it has been estimated that the fixed charges for the superheated station are less than those of the saturated station by 0.05d./kWh(E), at 80% load factor. If the cost of oil fuel is 2d./therm, the electrical power cost would be the same from either station. Since the C.E.A. were charged 3½d./therm for oil fuel in 1954-55,[24] the conclusion is that superheating is not likely to be economically attractive.

The development of suitable turbines for use with dry saturated steam should not present any serious difficulties. It may well be attractive to use a mixed station, the turbines being specially designed to use either dry saturated or superheated steam. In this case the superheaters would only be used at times of peak load and so generate an additional 30% of electricity. This would ease one of the main problems which have to be faced when reactors form a large proportion of the total generation capacity, since the cost of nuclear generated electricity is very sensitive to load factor.

The Single-zone Reactor

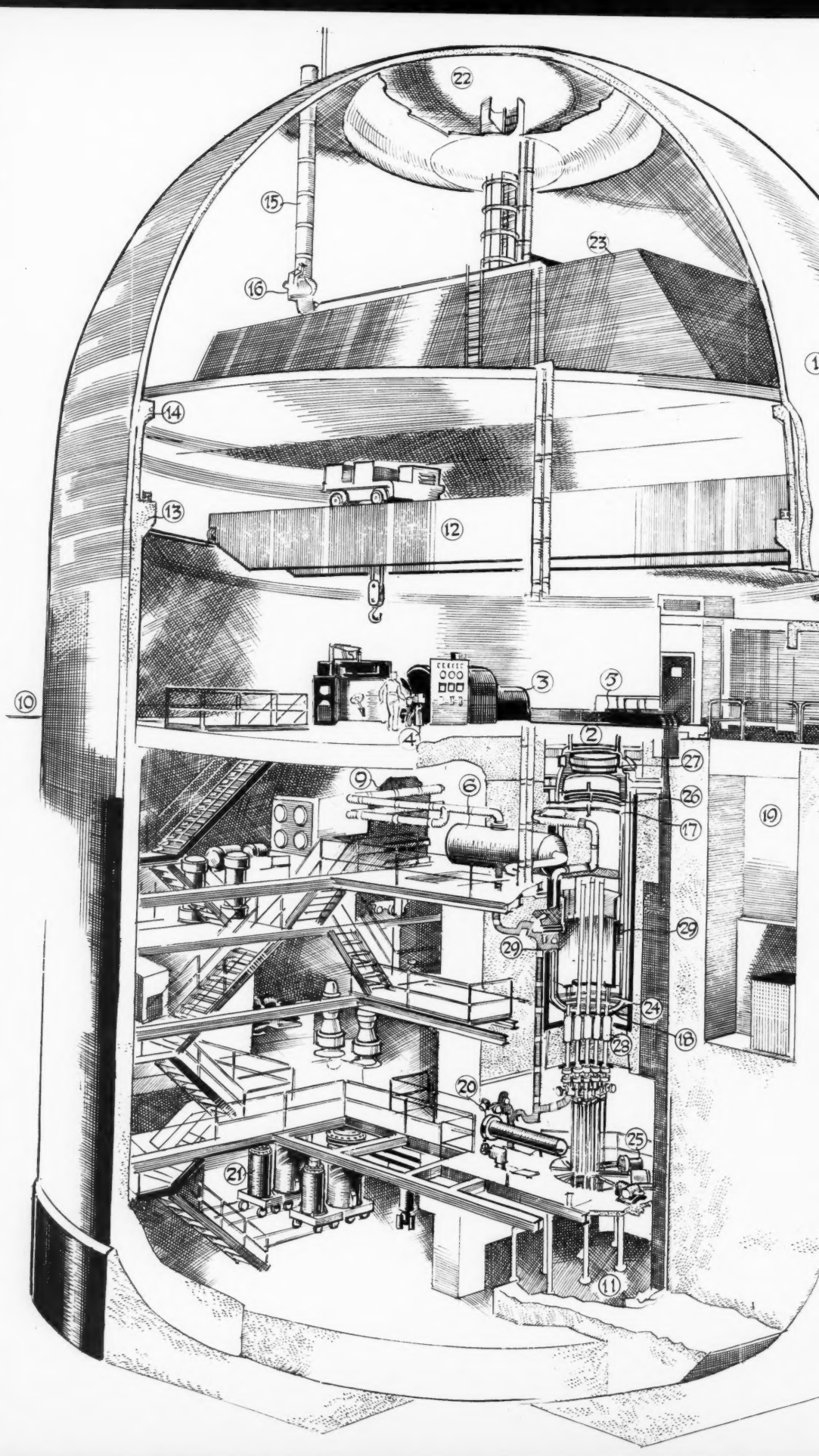
In the first part of this article (*Nuclear Engineering*, 2, April, p. 146) it was concluded that it was difficult to justify the development of the single-zone reactor as an end in

The World's Reactors

No. 13 EBWR

KEY

1. Containment shell
2. Reactor
3. Turbo-generator
4. Turbo-governor control
5. Fuel replacement assembly
6. Dryer, and emergency cooler
7. Air-lock doors
8. Control room
9. Main condenser, cooling (booster) pumps and filters
10. Ground level
11. Steel supporting columns and reactor vessel
12. Rotating crane (20-ton)
13. Concrete haunch (supporting crane rail)
14. Concrete haunch supporting reservoir
15. Air conditioning exhaust stack
16. Automatic damper for 15
17. Boric acid l.p. injector ring
18. Boric acid h.p. injector ring
19. Mortuary (storage for irradiated elements)
20. Start-up heater
21. Water purification plant
22. 15,000-gal water tank (sprinkler system)
23. Overhead water reservoir
24. Control rods (reactor vessel)
25. Control rods (motors)
26. Steam ring
27. Shield plug
28. Integral shielding
29. Feedwater ring
30. Main entrance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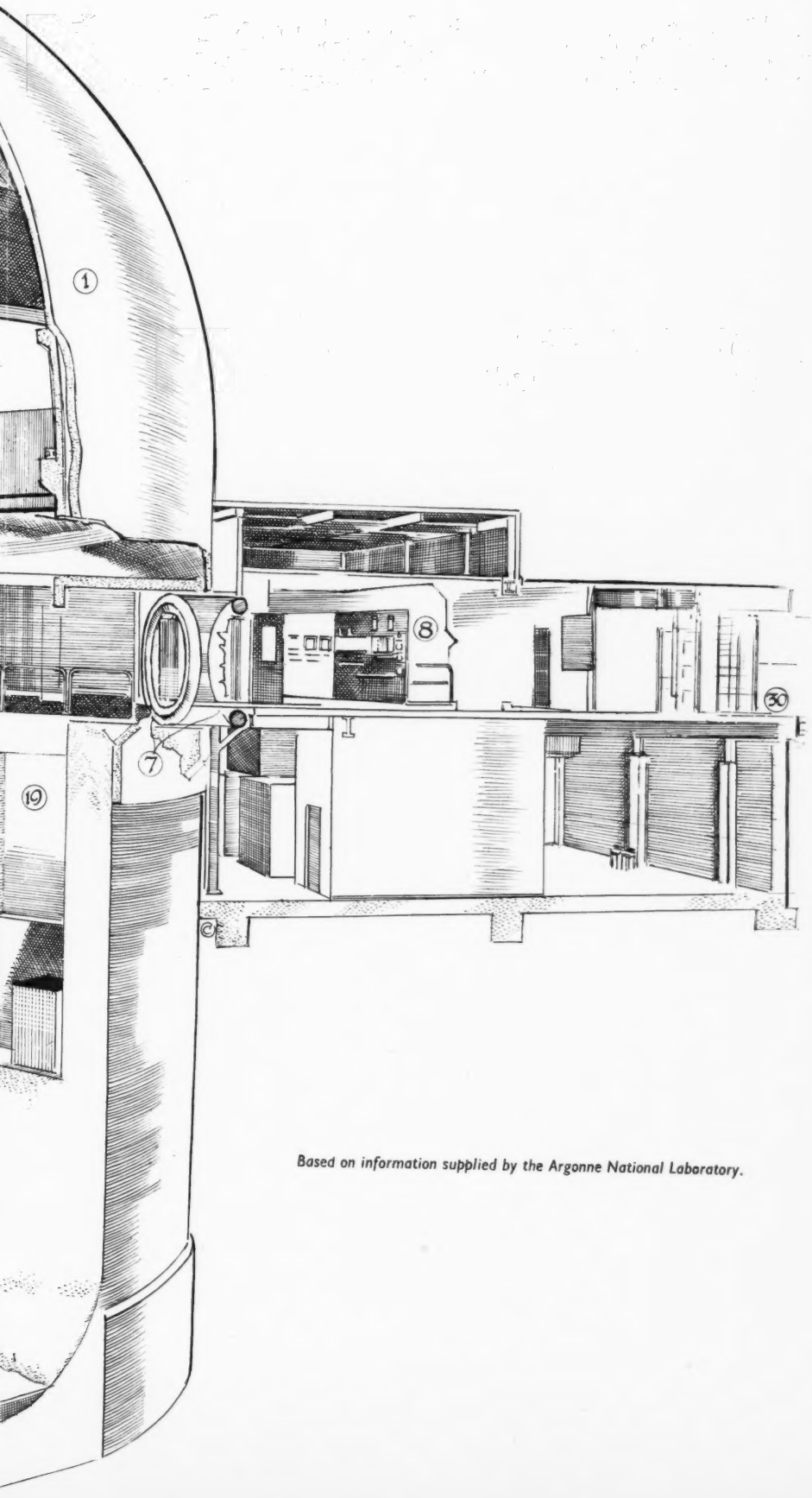
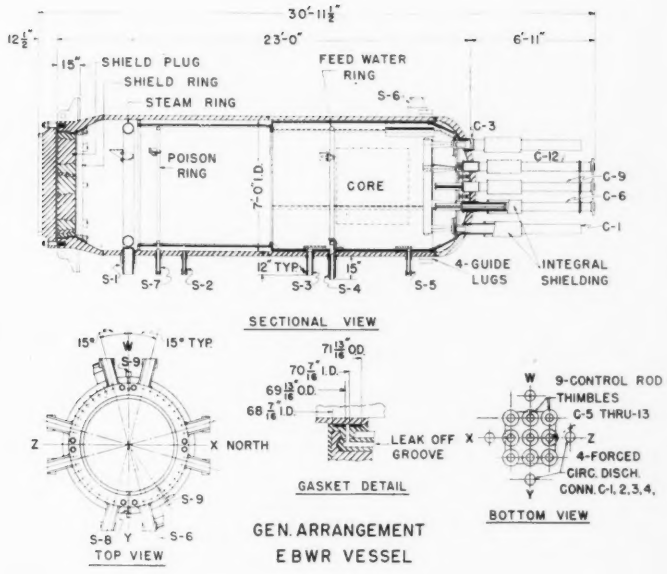


Based on information supplied by the Argonne National Laboratory.

The World's Reactors

No. 13 EBWR

TYPE :	Thermal heterogeneous.
PURPOSE :	Experimental power reactor using live steam.
LOCATION :	Argonne National Laboratory, Lemont, U.S.A.
OPERATION :	Diverged : Dec. 1, 1956. Opened: Feb. 9, 1957.
RATING :	20MW (heat), 5 MW (electrical).
FUEL :	Enriched and natural uranium. Average U^{235} content: 1.4%. U^{235} content of enriched elements: 1.44%. Total investment: 6.1 tons. Assembly composition: 6 plates of U–Zr–Nb alloy. Cladding: Zircaloy–2, 0.020 in. thickness. Plate dimensions: 54 in. × $3\frac{5}{8}$ in. × 0.214 in. and 54 in. × $3\frac{5}{8}$ in. × 0.279 in.
CORE :	Volume: 4 ft dia. × 4 ft 6 in. high. Fuel element assemblies: 106 enriched, 8 natural.
MODERATOR :	Light water.
PRESSURE VESSEL :	Material: Al killed steel, SA—212 Grade B. Cladding: 0.109 in. stainless steel type 304. Dimensions: 7 ft i.d. × 23 ft high. Wall thickness: $2\frac{3}{8}$ in.
COOLANT :	Light water. Inlet temp.: 110°F. Outlet temp.: 488°F. Top pressure: 600 p.s.i.g. Flow: 60,600 lb/h.
CIRCULATION :	Pumps: two vertical shaft, 8-stage centrifugal. Rating: 90,000 lb/h, 730 p.s.i.g., 190°F, 150 h.p. 3,550 r.p.m.
CONTROL :	Number of rods: 9, 5 hafnium, 4 boron. Hafnium rods: Hafnium–Zircaloy–2 alloy, cruciform shape. Dimensions: 10 in. × 10 in. × $\frac{1}{8}$ in. thick, 46 in. long. Weight with end pieces: 97 lb. Boron rods: 2% in stainless steel. Dimensions: similar to hafnium but $\frac{1}{4}$ in. thick. Weight: 141 lb.
STEAM DRYER :	Material: Stainless steel type 304. Dimensions: 3 ft i.d × 6 ft long. Wall thickness: $1^{5}/_{16}$ in.
SHIELDING :	Thermal shield in p.v.: 1 in. borated stainless steel. 3 in. stainless steel wool and concrete. Overall radial thickness: 8 ft $3\frac{1}{2}$ in.
EMERGENCY SHUT-DOWN :	160 gal sat. boric acid soln. at 1,600 p.s.i.g., injected into bottom of vessel. Boric acid spray at top.
TURBINE :	Pressure at T.S.V.: 560 p.s.i.g. Temp.: 482°F. Flow: 62,700 lb/h.
ALTERNATOR :	Rating: 5,000 kW, 60 c/s, 3,600 r.p.m., 4,160 V, 6,250 kVA at 0.8 p.f.
CONTAINMENT :	Steel shell ellipsoidal in shape. Dimensions: 80 ft dia. × 119 ft high. Design pressure (internal): 15 p.s.i.g. Leakage: <100 ft³/day.



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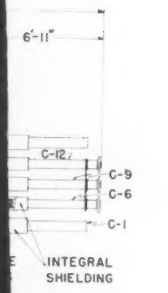
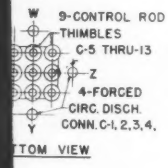
No. 2. *CP5* (*May*, 1956)
No. 3. *NRX* (*June*, 1956)
No. 4. *DIMPLE* (*August*, 1956)
No. 5. *ZEUS* (*September*, 1956)
No. 6. *CALDER HALL* (*October and December*, 1956)
No. 7. *RUSSIAN 5 MW* (*November*, 1956)
No. 8. *DIDO* (*January*, 1957)
No. 9. *THE SOUTH OF SCOTLAND ELECTRICITY BOARD STATION* (*February*, 1957)
No. 10. *BERKELEY POWER STATION* (*March*, 1957)
No. 11. *BRADWELL POWER STATION* (*April*, 1957)
No. 12. *DOUNREAY FAST REACTOR* (*June*, 1957)





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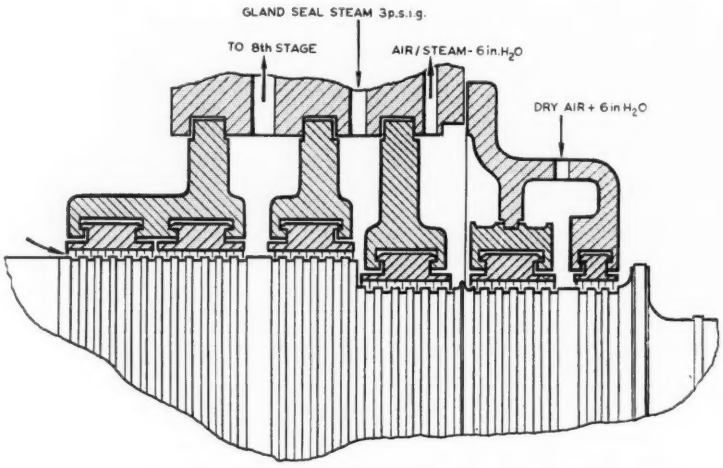

Diagram showing gland sealing arrangements for h.p. end of turbine shaft.

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itself since it did not apparently possess one of the principal advantages of the two-zone breeder system, viz., that of low fissile material inventory. Nevertheless the single-zone breeder reactor has an advantage in that one of the problems of the two-zone reactor, the provision of a corrosion resistant, neutron transparent window, has been eliminated. In addition, the slurry problem should have been eased as the ThO_2 concentration is reduced from its value of 1000 g/l in the two-zone reactor to 200-500 g/l. Therefore, the single-zone reactor could be regarded as worthy of development as a forerunner of the two-zone system, which must remain the ultimate goal.

The Westinghouse Electric Corporation in association with the Pennsylvania Power and Light Corporation are developing a large single-zone breeder system (The Pennsylvania Advanced Reactor—P.A.R.) as part of the U.S. demonstration programme. The system, together with the research programme associated with it, have been recently described.[25] The flowsheet and principal parameters involved are given in Fig. 7. The power cost estimates are not yet available.

It is interesting to note that superheating of the steam is not proposed; a thermal efficiency of 27.5% is expected using dry saturated steam at 400 p.s.i.a. It is hoped to have this reactor with an output of 150 MW(E) operating in 1962. The four heat removal circuits are separately valved, using 20 in. stop valves in pairs, and their inclusion is at present considered worthwhile since maintenance problems are eased even though their cost is very high. The figures given show that approximately 4 kg of U_{233} and Pu will be required per MW(E) in the primary loop circuits

Fig. 7.—Reference design of P.A.R. single-zone system (150MW(E)).

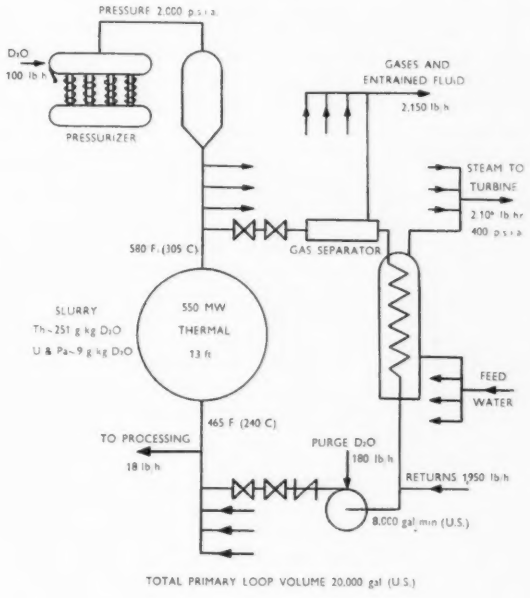
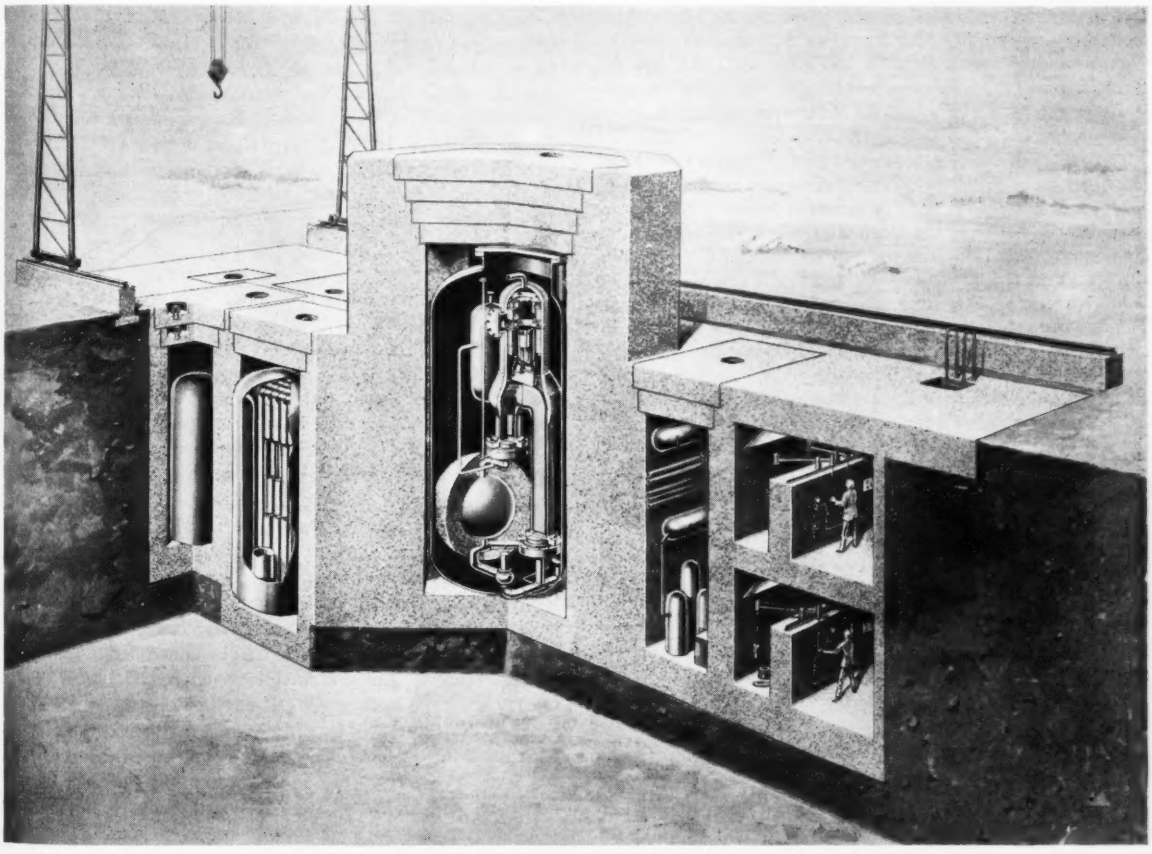


Fig. 8.—Proposed layout of the Wolverine-Foster Wheeler reactor.



alone, and this provides some justification for the statement in the first part of this article where it was said that the fissile investment of the single-zone system would be 2½ to 3 times that of a two-zone system.

The research programme at Westinghouse is extensive, and is largely devoted to gaining experience in the circulation of slurries, and the development of equipment for their handling. So far, it would appear, they have experienced little difficulty in slurry handling. Corrosion/erosion is expected not to be a major problem in the external circuit, experience to date indicating losses less than 0.002 in./year at velocities of 30 ft/sec. This result is based upon more than 5,000 hours of successful slurry pumping in 200 gal/min loops, at reactor operating conditions. Smaller loops have been built for testing high head slurry make-up pumps and slurry let-down valves. A much larger loop of 4,000 gal/min is to be built which will in many respects resemble a half scale model of one of the four heat removal circuits in the reactor itself. This will be a major advance in scale on anything else which has previously been carried out.

The H.A.R. Burner Reactor

The need for small reactors in the 5-10 MW class has been illustrated in a recent article in *Nuclear Engineering*,[26] where it is shown that there are many applications of such systems provided that the cost of power generation is around 2d./unit at high load factors. It is unlikely that such small reactors situated in areas having a good fuel supply could compete with diesel plants at low load factors. It is suggested that the small reactor would perhaps form the base load in an integrated system. A reactor station could only compete with conventional methods of generation at low load factors, if there were grave difficulties concerning the supply and transport of fuel. In fact the reactor station may enable certain locations to be developed, which have so far not received attention because of either the lack of fuel or the difficulties and expense of its transport.

The merits of the H.A.R. system in this respect have been described in a previous part of this article, and such a system has been proposed for building in the U.S.A., as a joint project between the Wolverine Electric Corporation, Big Rapids, Michigan, and the Foster Wheeler Corporation of New York.[27] This is being built as part of the U.S. Demonstration programme, and the 10 MW(E) output is intended to supplement the output from diesel plants in a predominantly rural district. Fig. 8 shows the proposed layout. In this case it is proposed to superheat the steam, and the steam at the turbine will be at 825°F and 530 p.s.i. The entire reactor system will be contained in a vessel 15 ft diameter, 32 ft high. The fuel make-up will be at weekly intervals. Some chemical processing is envisaged, chiefly to remove large-sized particles of corrosion products and fission products. The system will operate at 2,000 p.s.i., the method of pressurization being by oxygen gas. The costs are estimated as below, for 76% load factor.

Reactor Plant ($ 3,575,000 @ 15%)	8 mill/kWh
Steam Plant ($ 1,500,000 @ 15%)	3.4
Operation and Maintenance and processing wastes	2.5
Oil for Superheater	1.3
U_{235} burned ($15 – $30/g)	2.2 – 4.5
U_{235} inventory, lease charge	.2 – .3
Total	17.6 – 20 mill/kWh

This is less than 2d./kWh, although a direct conversion is not entirely satisfactory due to the different capital and fuel costs and also amortization charges which may apply in this country. Foster Wheeler claim the advantages of the Homogeneous Aqueous Burner Reactor to include entirely liquid fuel handling, no shut down required for fuel changing, and, most important, the absence of complicated nuclear control equipment.

A detailed survey of fuel costs has been made by Kasten and Claiborne[28] in which both H_2O moderated and D_2O moderated reactors in 25 MW(E) size have been investigated using U_{235}. From a nuclear standpoint the burner reactor may be operated for 25 years without fuel processing. The minimum fuel cost quoted is 4 mill/kWh if U_{235} costs $15/g for a D_2O system, and is only slightly increased if H_2O is used as the moderator. This cost includes D_2O inventory losses, which are only 0.2 mill/kWh. This fuel cost is twice the Foster Wheeler figure quoted above. The discrepancy can be partly accounted for as the Foster Wheeler plant uses superheating which costs 1.3 mill/kWh for fuel, and increases the thermal efficiency of the station. Both these factors would lower the U_{235} cost/kWh. In addition the F.W. figures are probably for 100% U_{235}, whereas Kasten and Claiborne assumed the use of 90% U_{235} (10% U_{238}) and they have had to include the additional U_{235} feed needed to overcome the poisoning due to the U_{238} and higher isotope captures. At the end of the 25-year period the proportion of U_{235} in the fuel would have fallen to 12% of the total uranium present in their case.

Homogeneous Systems Proposed or Built

The many types of homogeneous systems either proposed or built are listed in Table 4 taken from the paper presented to the B.N.E.C. and the Institution of Chemical Engineers.[16]

The first models at Los Alamos consisted of a container of enriched uranyl sulphate or nitrate solution surrounded by a reflector and became known as "water boilers" because of the bubbles of gas produced by the radiation decomposition of the water. Successive models—Low Power Water Boiler (LOPO), Higher Power (HYPO) and Super Power (SUPO)—were developed for research purposes, the last being capable of operating at 45 kW. Many other "water-boilers" research reactors have since been built.

"Water boilers" operate around atmospheric pressure and at temperatures below boiling. To produce temperatures high enough for power generation pressure operation is required and the first pilot model two-zone power reactor was the Homogeneous Reactor Experiment (HRE). This reactor operated for about 2,000 hours at power levels up to 1,600 kW,[29] the circuit being shown in Fig. 9. It demonstrated that the large negative temperature coefficient was sufficient for control of the reactor and that control rods and shut-off rods could be omitted. The power output was shown to be self regulating to power demand from the secondary side of the heat exchangers. HRE was also used to demonstrate that low concentrations of copper ion[30] would catalyse the recombination of dissolved hydrogen and oxygen in solution and so enable the radiation decomposition reaction of water to be controlled. A larger power version, called the Homogeneous Reactor Test (HRT) has been built at Oak Ridge[31] to operate at 10 MW heat. This model will extend the information on the effects of radiation on corrosion, the problem of continuous removal of neutron poisons and corrosion products from the core, on the reliability of components and on the efficiency of methods of remote maintenance. Tentative

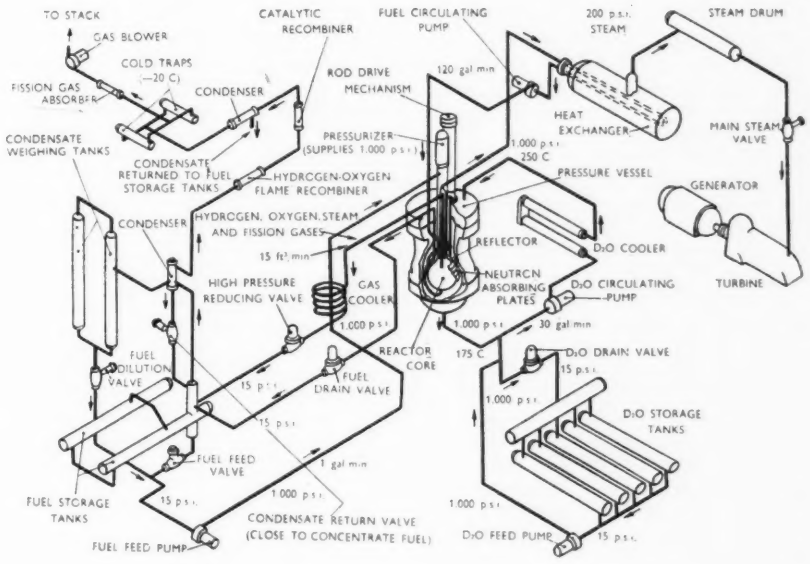


Fig. 9.—Flowsheet of H.R.E.

proposals for a large scale two-zone power producer have been made[32] but these do not appear to have progressed further than a feasibility study.

The Pennsylvania Advanced Reactor Project (PAR)[25] and the Foster Wheeler-Wolverine reactor[27] have been described previously. The Dutch project at KEMA, Arnhem,[33] aims at producing a reactor (SUSPOP) operating on a single zone UO_2 slurry system.

TABLE 4
Homogeneous Aqueous Reactors

Reactor	Location	Date	Function	Fuel	Fuel inventory	Moderator	Flux	Power		Coolant exit		Core dimensions (in. diam.)	Core material
								Heat	Electric	Temp. (°)	Pressure		
LOPO (low-power water boiler)	Los Alamos	1944	Research	UO_2SO_4 (14%E)	0.5 kg	H_2O		0.05 W	0	39	Atmos.	12	S. steel
HYPO (high-power water boiler)	Los Alamos	1944	Research	$UO_2(NO_3)_2$ (14%E)	0.8 kg	H_2O	3×10^{11}	6 kW	0	55	Atmos.	12	S. steel
SUPO (super-power water boiler)	Los Alamos	1951	Research	$UO_2(NO_3)_2$ (14%E)	0.8 kg	H_2O	2×10^{12}	45 kW	0	85	Atmos.	12	S. steel
H.R.E. (homogeneous reactor experiment)	Oak Ridge	1952	Development	UO_2SO_4 (90%E)	3.2 kg	H_2O	2×10^{13}	1,600 kW	150 kW	250	1,000 p.s.i.	18	S. steel
W.B.N.S. (water-boiler neutron source)	Downey, Calif.	1952	Neutron source	$UO_2(NO_3)_2$ (90%E)	0.8 kg	H_2O	10^9	2 W	0			12	S. steel
N.C.S.R. (North Carolina State reactor)	Raleigh	1953	Research	UO_2SO_4 (90%E)	1.0	H_2O	5×10^{11}	10 kW	0	80	Atmos.	15	S. steel
L.W.B. (Livermore water boiler)	Livermore, Calif.	1953	Neutron source	UO_2SO_4	0.7 kg	H_2O	2×10^{10}	0.5 kW	0	15		12	S. steel
ZETR. (zero energy thermal reactor)	Harwell	1956	Research	UO_2F_2 (U_{233} or U_{235}) or $PuO_2(NO_3)_2$	Variable	H_2O	4×10^8	0	0			12	S. steel
LAPRE—I (Los Alamos power experiment)	Los Alamos	1956	Power prototype	UO_2HPO_4 (90%E)	9.0 kg	H_2O	2×10^{13}	2,000 kW	0	430	3,900 p.s.i.	15	Gold-plated steel
UCLA Medical	Los Angeles	1956	Research and treatment	UO_2SO_4 (highly enriched)	0.925 kg	H_2O	2×10^{12}	50 kW	0			12	S. steel
Armour Research Foundation	Chicago	1956	Irradiation source	UO_2SO_4	0.8 kg	H_2O	2×10^{12}	50 kW	0	44	65 p.s.i.	12	S. steel
Gamma Corporation ..	Mansfield, Mass.	1956	Neutron source			H_2O		1 MW	0				S. steel
H.R.T. (homogeneous reactor test)	Oak Ridge	1956	Power prototype (breeder)	UO_2SO_4 (90%E)	5.2 kg	D_2O	7×10^{13}	2 MW	300 kW	300	2,000 p.s.i.	32	Zirc-aloy
KEWB	Santa Susana, Calif.	1956	Safety research	UO_2SO_4									
LAPRE—II	Los Alamos	1956	Power prototype (burner)	UO_2HPO_4 (90%E)	7.7 kg	H_2O	10^{13}	1,300 kW	0	430	500 p.s.i.	15	Gold-plated steel
BABYPOP	K.E.M.A., Arnhem	1957	Research	UO_2 or U_3O_8 suspension		H_2O		0	0				Steel
Japan research reactor ..	Tokio	1957	Neutron source	UO_2SO_4	0.8 kg	H_2O	10^{12}	50 kW	0	45	20 p.s.i.	15	S. steel
WOLVERINE	Hersey, Mich.	1959	Power (burner)	UO_2SO_4 (90%E)		H_2O		Reactor 27 MW Superheat 7 MW	10 MW	300	1,900 p.s.i.	12	S. steel
PAR (Pennsylvania advanced reactor)	Eastern Pennsylvania	1962	Power	ThO_2–UO_2 suspension		D_2O			150 MW				S. steel
SUSPOP	Arnhem		Development	UO_2 suspension		H_2O	10^{13}	250 kW	—	250	750 p.s.i.		Steel

The H.A.R. in a Large-scale Programme

If an expanding programme of electrical generation is to be achieved by means of the two-zone breeder homogeneous system it is clear that regular supplies of U_{233} would be required for start-up purposes. Unfortunately U_{233} must be made by neutron irradiation of Th_{232} in reactors. Such reactors, termed convertors, would consume fissile U_{235} from a diffusion plant or Pu produced by the gas cooled reactor stations now being erected. In later years some U_{233} could be supplied by the earlier breeder reactors, since if their conversion factor is greater than unity they will produce more U_{233} than they consume.

A possible method of achieving an expanding programme is to have a regular annual supply of either U_{235} or Pu. Initially a few homogeneous aqueous convertor stations would be built, and these would then supply a regular amount of U_{233} to enable breeder stations to be started up at intervals.

If a hypothetical case is considered of such a power programme, and it is assumed that 15,000 MW(E) have to be installed in 15 years (an average annual installation of 1,000 MW), then both the feed rate of fissile material required annually and the heavy water requirements must be determined.

Let the Convertor Reactor Fissile Investment be .. .. .. I kg/MW(E)
Convertor Reactor Fissile Consumption be .. K kg/MW(E)/year
Convertor Reactor Produce be .. .. .. A kg U_{233}/MW(E)/year
and let the Breeder Reactor Fissile Investment be .. .. J kg/MW(E)
Let the Breeder Reactor Excess U_{233} production be .. E kg/MW(E)/year
Then if P is the annual supply of fissile material
and M = MW(E) installed Convertors at any time t
N = MW(E) installed Breeders at any time t
it can be shown that

$$P = I\frac{dM}{dt} + KM \text{ for the Convertor Stations}$$

and $$A.M + E.N = J\frac{dN}{dt} \text{ for the Breeder Stations.}$$

These two equations neglect the time for chemical processing of the fuel, but this is reasonable as the time occupied is small when continuous processing is used. It also assumes that the growth of stations is a continuous function, but over a period of 15 years this is justified since the steps involved are small. In addition the time to equilibrium after which U_{233} can be extracted continuously from the convertor reactors has been neglected, but this is of little account, being only of the order of 6 months.

The solutions to these equations are:—

$$M = \frac{P}{K}(1 - e^{-Kt/I})$$

$$N = \frac{API}{K}\left[\frac{1}{EI}(e^{Et/J} - 1) - \frac{1}{KJ + EI}(e^{Et/J} - e^{Kt/I})\right]$$

$$\text{Unless } E = 0 \text{ when } N = \frac{API}{K}\left[\frac{t}{IJ} - \frac{1}{KJ}(1 - e^{-Kt/I})\right]$$

To apply this to a particular system, employing Pu-U_{233} convertors, and two-zone U_{233}-Th_{232} breeders the following data can be used.

Convertor Reactors	Breeder Reactors
I = 2.4 kg/MW(E) K = 1.4 kg/MW(E) A = .85 kg/MW(E)/year	J = 1.25 kg/MW(E) E = .046 kg/MW(E)/year
(A conversion factor of .6 has been assumed, 90% load factor.)	(A conversion factor of 1.05 has been assumed, 80% load factor.)

Figures 10(a) and (b) show the results obtained. An annual supply of about 1,600 kg of Pu would be needed, to ensure that 15,000 MW would be installed within 15 years. The growth of power varies from 700 MW/year at the commencement to 1,300 MW/year at the end of the period. At the end of the 15 years, about 1,000 MW would

Réacteur Aqueux Homogène

Un article précédent a défini les systèmes aqueux homogènes et a montré leurs mérites relatifs. (Nuclear Engineering, Avril 1957.) Ce second article montre les problèmes qui se présentent dans de tels systèmes, notamment la corrosion, la manutention des boues, la sûreté des organes, l'entretien, méthode de fabrication, production du gaz et son enlèvement, ainsi que les moyens permettant de résoudre ces problèmes. Une description est donnée d'un système typique à deux zones; ce système est établi pour produire 100 MW d'électricité. Des réacteurs à zone simple et des réacteurs à brûleurs sont décrits, avec référence particulière aux systèmes de Westinghouse et de Foster Wheeler. Une liste a été établie des réacteurs homogènes qui ont été soit proposés, soit construits. L'emploi de ce système à l'échelle nationale est envisagé et on montre que le système pourrait être appliqué économiquement pour la production de l'énergie sur une grande échelle.

Der Homogene Reaktor mit Flüssigem Kern

Ein früherer Aufsatz gab Definitionen für die mit flüssigem Kern arbeitenden Systeme und besprach ihre Vor- und Nachteile (Nuclear Engg., April 1957). Dieser zweite Aufsatz zeigt die Probleme, die bei solchen Systemen auftreten, nämlich die Fragen der Korrosion, der Behandlung der Aufschlämmungen, der Zuverlässigkeit der Komponenten, der Unterhaltung, der Vorbehandlung und der Entwicklung und Ableitung der Gase, und ferner die verschiedenen Wege, auf denen diese Probleme gelöst werden können. Es wird die Beschreibung eines typischen Zwei-Zonen-Systems gebracht, das für die Erzeugung einer Leistung von 100 MW konstruiert worden ist. Ein-Zonen-Reaktoren und Brenner-Reaktoren werden beschrieben, wobei auf die Westinghouse und Foster Wheeler Konstruktionen besonders Bezug genommen wird. In Tabellenform wird eine Liste der homogenen Reaktoren gebracht, die entweder vorgeschlagen wurden oder bereits gebaut worden sind. Die Anwendung des Systems auf nationaler Basis wird einer Betrachtung unterzogen und dann gezeigt, dass das System in wirtschaftlicher Weise für die Erzeugung elektrischer Kraft im Grossen angewendet werden kann.

El Reactor Acuoso Homogeneo

En un artículo anterior se hizo una definición de los sistemas acuosos homogéneos y se discutieron sus relativos méritos. (Nuclear Engineering, Abril de 1957.) Este segundo artículo reseña los problemas que surgen en tales sistemas, es decir, corrosión, manejo de sedimentos, seguridad de componentes, mantenimiento, procesado y producción de gas y remoción, y las formas en que estos problemas pueden ser solucionados. Se ofrece una descripción de un sistema típico de dos zonas; este sistema ha sido diseñado para generar 100 MW de electricidad. Se describen reactores de zona única y reactores de quemadores, con particular referencia a los diseños de Westinghouse y Foster Wheeler. Se da una lista tabulada de reactores homogéneos que han sido construidos o que se propone construir. El uso del sistema en escala nacional es considerado, y se muestra que el sistema podría ser aplicado económicamente a la generación de fuerza en gran escala.

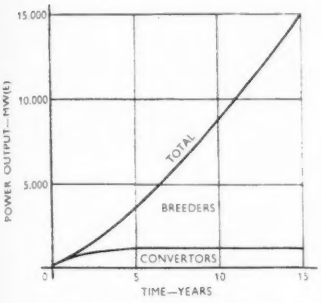


Fig. 10(a)—Power output.

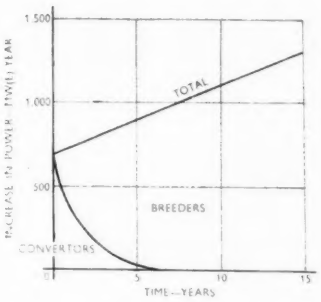


Fig. 10(b)—Growth of power output.

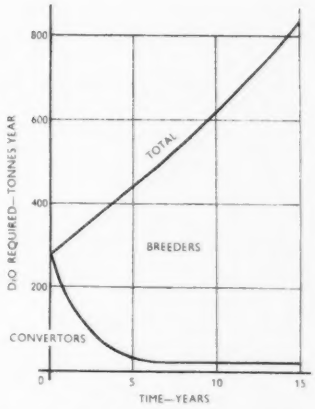


Fig. 10(c)—Annual D_2O requirements.

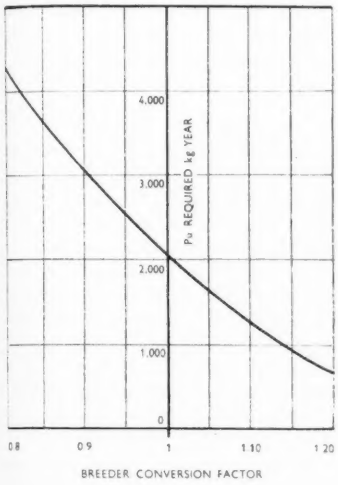


Fig. 10(d)—Effect of variation of breeder conversion factor upon annual requirements of Pu.

be generated by convertor stations and 14,000 MW by breeder stations.

By an extension of the above the annual requirements of D_2O can be estimated and the results are shown in Fig. 10(c). It has been assumed here that as well as supplying the initial requirements at start-up, the annual loss is 5%. If this annual loss is reduced, the savings in D_2O are considerable, as 300 of the 800 tonnes required in the final year are losses.

Variation of the conversion factor of the breeder reactor has a considerable influence on the annual requirement of fissile material. This is illustrated in Fig. 10(d). If the conversion factor of the breeder reactors is less than unity, then the convertor stations are supplying these reactors with a continuous feed of make-up U_{233} as well as supplying the initial needs of the new installations. Very approximately, a change in the conversion factor of the breeder system of 0.01 alters the Pu demand by 100 kg/year.

Conclusions

These results are presented mainly for illustrative purposes, and are intended to show that the Homogeneous Aqueous system is capable of being economically employed on a large scale, as well as on a limited experimental or prototype scale provided the solutions to the problems enumerated are found. It was stated in a recent issue of *Nuclear Engineering*[34] that the O.E.E.C. Steering Committee for Nuclear Energy has recommended that the Homogeneous Aqueous Reactor should be included in the co-operative development programme proposed in its report.[34]

Acknowledgments are due to Oak Ridge National Laboratory, Tennessee, U.S.A., for the use of Fig. 9 and to Foster Wheeler Corporation, New York, U.S.A., for the use of Fig. 8.

Errata to Part I of Article, *Nuclear Engineering*, Vol. 2, No. 13, April, 1957.

Fig. 1. Reactor Diameter should be 4 **feet,** not 4 **inches** as shown.

Fig. 2(b). A connection should be inserted between the inlet side of the blanket heat exchanger and the top left-hand side of the pressure vessel.

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DOUNREAY

Part II

Following the description of the fast reactor in a previous issue, this article gives particulars of some of the other services available at this establishment including materials testing, chemical processing and ancillary services.

FOLLOWING the description of the fast reactor (*Nuclear Engineering*, June, 1957) some mention should be made of the Materials Testing Reactor (DMTR) which is being built to facilitate " in-pile " experiments on fuel elements, coolant loops and constructional materials under conditions sufficiently arduous to represent whole life operation in a power reactor.

D.M.T.R. is a heavy-water moderated, high-flux (10^{14} n/cm^2-sec) reactor which differs only in detail from DIDO and PLUTO, the corresponding Harwell reactors. A comprehensive description of DIDO was given in *Nuclear Engineering* for January, 1957, so that it will suffice to note certain of the detail differences, notably the core lattice (26 elements arranged 4-6-6-6-4 against DIDO's 25 arranged 4-6-5-6-4) and the number of coarse control arms (7 against DIDO's 6).

The most important difference, however, is in the experimental facilities which are fewer in number and larger to enable bigger test rigs to be accommodated. A particular feature of DMTR is the arrangement of large diameter straight-through holes in pairs, so that complete loops can be installed. Table 1 gives comparative details of the experimental facilities—PLUTO and DMTR are similar.

The difference is most marked in the horizontal facilities which consist of four large (7 in.) horizontal pipes passing straight through the main tank. Each has a return pipe vertically beneath it so that, if necessary, four complete loops could be accommodated. This arrangement has resulted in a rectangular cross-section for the main shielding block, in place of the 12-sided design of DIDO.

Provision is made for temporary flooring to be built at any desired level around the main block, to accommodate the large and heavy components making up a test loop.

As in the case of DIDO, PLUTO and the Australian research reactor, the main contractors are Head Wrightson Processes Ltd. The containment building for the reactor circuit is, however, manufactured by the Motherwell Bridge and Engineering Co. Ltd. who built the sphere for the fast reactor. There are other detail differences in suppliers, the helium blowers, for example, being supplied by Northey Compressors Ltd., the use of rotary blowers resulting in a considerable saving in space.

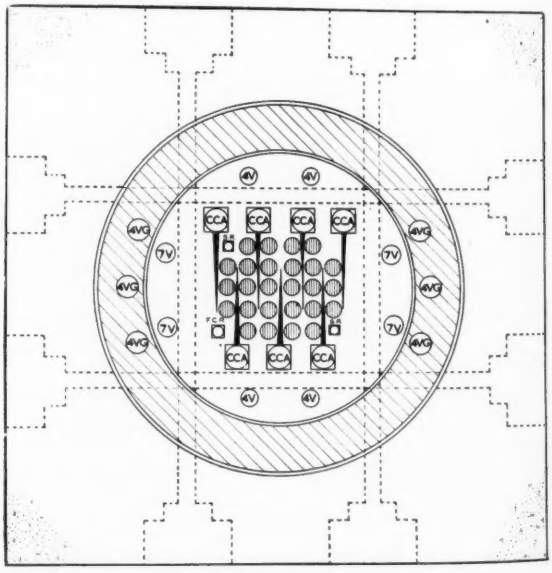
TABLE 1. COMPARISON OF EXPERIMENTAL FACILITIES

Description	Size	DIDO	DMTR
Horizontal			
In D_2O	10 in. dia.	1	–
In D_2O	6 in. dia.	1	–
In D_2O	4 in. dia.	6	–
In D_2O (right through)	7 in. dia.	–	4
In D_2O (right through)	Oval 4 in. x 2 in.	1	–
In graphite (right through)	Rectangular 8 in. x 12 in.	2	–
Vertical			
In D_2O	7 in. dia.	–	4
	6 in. dia.	4	–
	4 in. dia.	5	–
	2 in. dia.	9	–
In graphite	10 in. dia.	2	–
	6 in. dia.	6	–
	4 in. dia.	2	6
Thermal Column	5 ft. x 5 ft.	1	–
	4 in. x 4 in.	9	–

The M.T.R. Programme

In drawing up the experimental programme, highest priority will be awarded to those projects which will provide the maximum information to the design teams of the Industrial Group and their commercial collaborators. A minimum of six holes has been allocated to studies of the behaviour of different types of fuel under various conditions of temperature, stress, and burn-up rate, i.e., the tendency of the fuel to grow or swell under irradiation, and changes in thermal conductivity, hardness, mechanical strength and metallurgical structure, also on the ability of various types of can to withstand deformation. A further hole will be used for proving tests on fuel elements designed for commercial reactors, such as the C.E.A. stations.

Three large holes will be available for research into the effects of irradiation on the corrosion properties of coolants such as Na, NaK, CO_2 and H_2. Smaller facilities will be set aside for specialized problems of irradiation chemistry and for the development of analysis techniques dependent upon isotope formation.



Block plan of DMTR showing facilities :
CCA coarse control arms 7V and 4V 7 in. and 4 in. vertical facilities in D_2O. 4VG 4 in. vertical facilities in graphite. Dotted lines show the four 7 in. horizontal facilities in D_2O. There is a return pipe under each so that a complete loop can be tested.

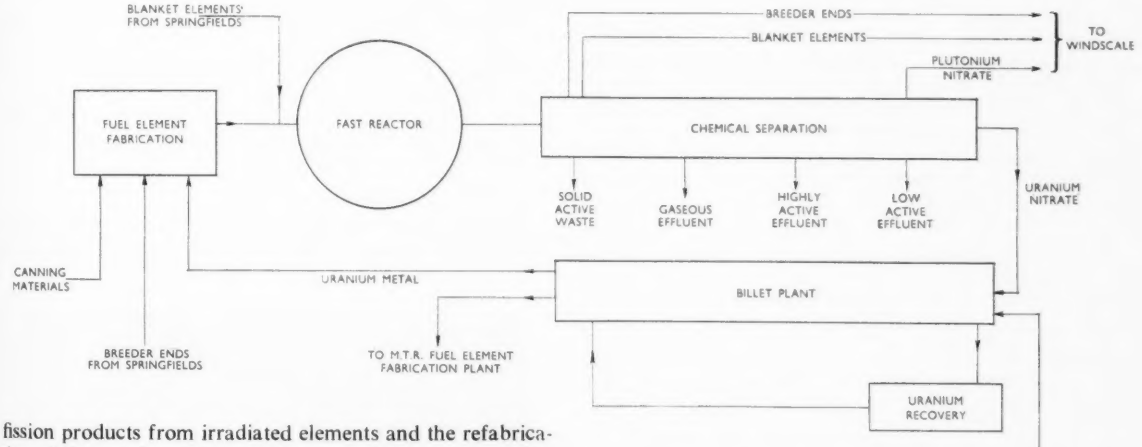
The behaviour of graphite under irradiation is of such fundamental importance in thermal reactor design that investigations on this topic alone will occupy one or two holes. The remaining facilities will be devoted to measurement of the mechanical and physical properties of structural materials such as alloys of beryllium, zirconium, niobium, molybdenum and magnesium of interest as container materials, and also various types of steel used in pressure shells and support structures. Studies will include the post irradiation examination of irradiated material, and measurement of properties such as tensile strength, creep resistance, thermal and electrical conductivity and thermal expansion on specimens during irradiation.

It must be stressed that the irradiation programme represents only the final phase in a research programme of some magnitude. Irradiation tests are expensive, and the demand far exceeds supply. Hence the other Industrial Group's laboratories have already investigated numerous problems appertaining to the preliminary selection of materials for reactor use, and only those materials meriting further consideration will be passed forward to the irradiation testing stage. At the same time it must be emphasized that the maximum value is to be obtained from irradiation experiments only if control experiments are carried on out-of-pile. The function of the M.T.R. research group will not, therefore, be limited to the design and conduct of experiments in the reactor. An essential corollary will be the simulation of in-pile conditions—less neutron flux—in the laboratory, for comparison purposes.

Lowering the A.P.V. aluminium vessel into position during erection. The 7 in. horizontal facilities can be clearly seen.

Reactor Fuel Cycles

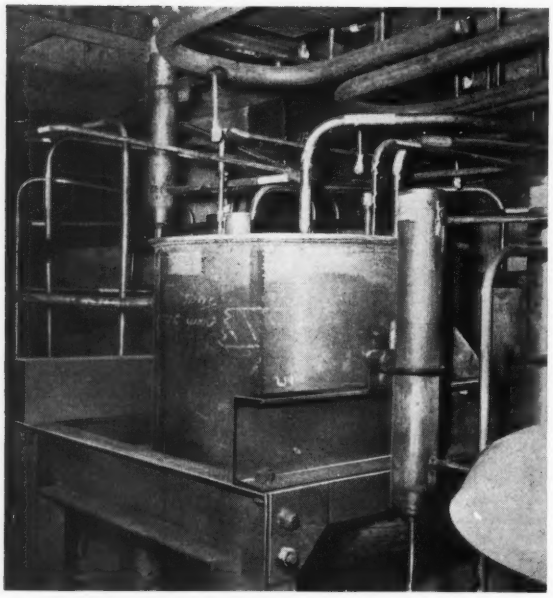
Fuel recycling for the two reactors at Dounreay and the other highly enriched fuel reactors necessitates a complex chemical organization for the removal of plutonium and fission products from irradiated elements and the refabrication of the uranium into new elements. The accompanying diagram shows, in simplified form, the fuel cycle for the fast reactor; that for the M.T.R.s being similar in general principles. The billet plant for the production of metallic uranium is common to both reactors, as are the ancillary services such as effluent disposal, but otherwise the two cycles are separate.

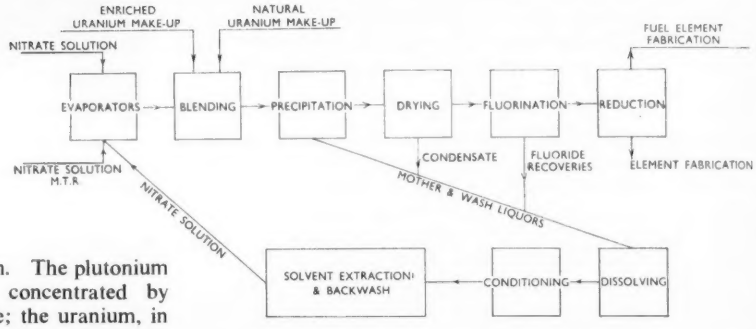


Simplified fuel cycle for the fast reactor.

Chemical Separation

After removal from the fast reactor, fuel elements, embedded in lead, are placed in stainless steel containers and are then transferred to the cooling pond from which they enter the chemical separation plant. This plant has a deep tiled pond at one end, and the elements are mechanically stripped of their cans under water, the bare uranium metal being then transferred to a steam-heated continuous dissolver and dissolved in nitric acid. The solution then passes through a sludge remover, continuous sampler and constant volume feeder to pulsed mixer-settler extraction units. Here a counter-current of tributyl phosphate extracts plutonium and uranium from the bulk of the fission products, being then recovered from the solvent by a back-washing process with nitric acid and the cycle is repeated for the removal of the remainder of the fission products. A third solvent extraction cycle





(Above) Part of the chemical separation plant showing stainless steel vessels and pipework. (Right) Simplified flow diagram of uranium metal production from nitrate solution.

separates the uranium from the plutonium. The plutonium nitrate, after further purification, is concentrated by evaporation and dispatched to Windscale; the uranium, in the form of uranyl nitrate, is held in storage tanks from which it is transferred as required to the metal production plant. The apparatus throughout is in stainless steel and the requirements for welding were extremely rigorous. At the "hot" end of the process all apparatus is shielded by 4 ft of concrete.

The M.T.R. chemical separation plant differs in many details from the fast reactor plant; it is arranged for batch, instead of continuous, operation and so the amount of fissile material being processed at any time can be accurately controlled. The fast reactor plant has been designed throughout from the standpoint of sub-critical geometry of all vessels.

Metal Production

Unlike the chemical separation plant, the metal production building handles materials from which beta- and gamma-active fission products have been removed, but it is still necessary to operate in closed conditions.

The accompanying diagram shows in schematic form the sequence of processes in the production of metal, which involves the conversion of the nitrate to hexafluoride, and the reduction with magnesium. It also shows the processes for the recovery of uranium from side-streams of the process, e.g., in the supernatant liquor at precipitation and in the slag formed during the billet formation. In addition, material for recovery arises from the fuel element production processes. These materials are processed in a recovery section through the stages of dissolution, filtration, solvent extraction (for removal of impurities) to give an aqueous solution of uranium pure enough to be fed back to the metal production process.

A second recovery line is installed to recover uranium from extraneous sources. This broadly follows the same lines as the normal recovery process, differing only in the initial treatment.

Process lines have been designed to give the maximum possible safety. All operations are carried out in dry-box lines placed at right angles to the main axis of the building which has long corridors on either side, each communicating with only one side of the line of dry boxes. One corridor is reserved for normal operation and gives access to the front face, which is of Perspex, fitted with gloves where necessary to give ease of handling and maximum visibility. The other corridor gives access to the back of the equipment for maintenance work or sampling. Ventilation is arranged as shown in the diagram, so that the flow of air is always away from the operator into the equipment.

In addition to the main operational lines the building has storage rooms for materials before and after processing, a gas bottle store for gases used in the process, an inactive feed preparation room, a health physics control room and office accommodation for plant supervisors, a small workshop and changing room accommodation.

Fuel Element Manufacture

At the time of visiting Dounreay the fast reactor element line was in course of commissioning and it is not possible to give a description. The general processes are, however,

Fuel element fabrication line for DMTR.

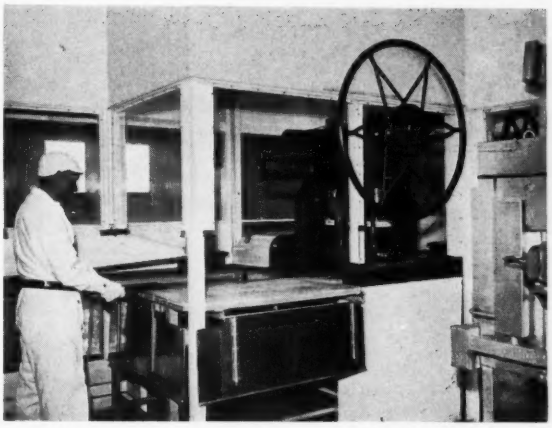
not unlike those involved in the manufacture of DMTR elements. The DMTR element consists of a brazed box assembly of ten curved fuel plates and two aluminium cover plates, separated by spacers at the edges. Each fuel plate consists of a thin plate of uranium-aluminium alloy, clad in aluminium.

A typical fuel element would conform to the following specification:—

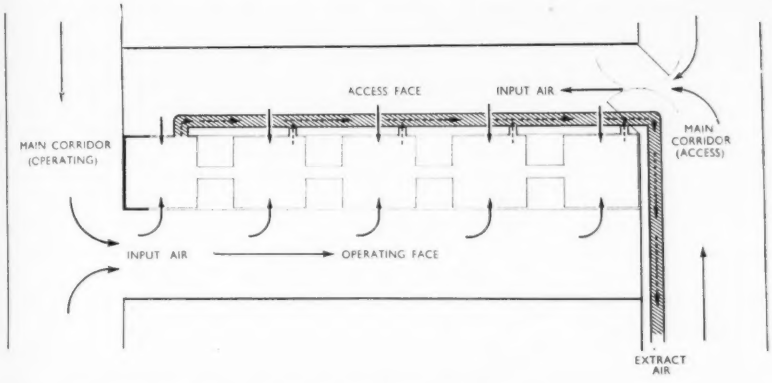
Overall length	5 ft $7\frac{7}{8}$ in.
Length of core	2 ft 1 in.
Weight of uranium 235 ..	100 g (approx.)
Fuel plate thickness	0.058 in.
Core thickness	0.018 in.
Spaces between fuel plates ..	0.177 in.
Radius of curvature of fuel plates	$5\frac{1}{2}$ in.

The uranium is alloyed with aluminium in a vacuum furnace and cast into billets, which are then rolled into strip and accurately punched to the required weight and dimensions. These are enclosed in an aluminium plate sandwich, welded round three sides, and rolled down to the finished thickness at 600°C. Following this they are assembled in a jig with channel sections of aluminium, wrapped with aluminium-silicon foil and the jig assembly is dipped into a flux bath which melts the aluminium-silicon alloy to produce a strong rigid assembly.

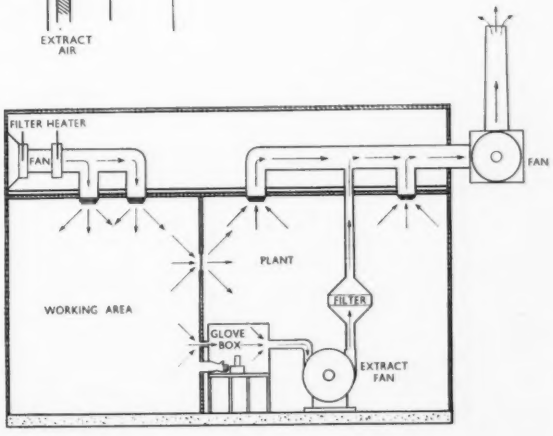
At all stages there is close inspection for dimensional accuracy including an X-ray examination to determine the location of the uranium plate in the sandwich.

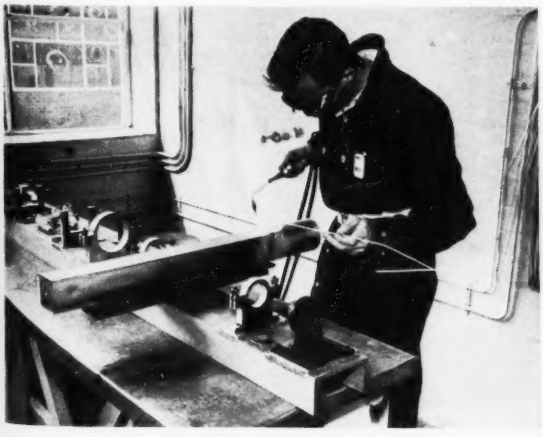


(Above) Rolling mill in fuel element production line.



(Left and below) Methods of ventilation.





Brazing DMTR fuel element ends onto boxes.

Effluent Disposal

One of the important functions of the Chemical Group is the disposal of active wastes, and the Highly Active Storage plant is the disposal centre, where the highly active effluent is stored in concentrated form and the low active effluent discharged to sea.

The Highly Active Store is a heavy reinforced concrete structure, with stainless steel storage tanks below ground level, which involved the removal of more than 4,000 tons of rock.

The highly active effluent is discharged to the building via two separate pipelines, one taking evaporable liquor and the other non-evaporable liquor, from the M.T.R., which contains sufficient aluminium nitrate to make evaporation inadvisable because of crystallization dangers. This non-evaporable liquor passes direct to storage and the evaporable liquor is directed to holding tanks in the

Jig assembly of DMTR fuel plates.

building. Thos. W. Ward were the main contractors for the stainless steel equipment in the building.

From the holding tanks the highly active liquor is transferred batchwise to a constant-volume feeder in the evaporation cell, and is then fed through a steam strip column, which removes the volatile tributyl phosphate and kerosene, and then to a continuous evaporator. The concentrated fission product solution is transferred to storage and the condensate from the evaporation is monitored and discharged to sea.

The plant is constructed so that all the active section of the plant is situated behind concrete biological shielding with all control equipment situated outside the shielding. Where there is a hold-up of a large volume of concentrated liquor in a vessel inside the evaporation cell, shield plates of mild steel are erected to reduce the thickness of the concrete shielding required.

In highly active plant the use of mechanical equipment, e.g. pumps and valves, is impracticable because of the radiation hazard involved in their maintenance, and vacuum lift techniques are used to carry out liquor transfers in the plant; the steam ejectors used being situated outside the biological shield for ease of maintenance. Precautions are taken in plant design to guard against active vapour or liquid being drawn outside the shield. Where liquids from various sources have two or more alternative lines of flow, flow distributors are used.

The concentrated active liquors in storage contain several important isotopes, e.g. Cs^{137} and Sr^{90}, which have industrial and medical uses. Provision is made in the plant for the withdrawal of liquor from the storage tanks and its transfer to a future extraction plant for isolating and purifying these isotopes.

Low Active Liquid Effluent

The low radioactive liquid wastes from all the chemical plants, reactors and active laboratories are discharged direct to two effluent holding pits and thence to sea. A tunnel is being constructed to take a pipeline out to sea for the discharge of low active effluent, the nature of the sea bed and difficult tidal conditions making it impracticable to adopt the Windscale pipeline method.

Each building neutralizes its effluent before sending it, via a cast iron drain pipe, to the lined effluent pits. The pumping is done by three pumps, which are situated adjacent to the pits. Pumping is commenced one hour after high tide to ensure that the effluent is diluted and drawn away from the shore.

To ensure that the requirements are met a representative sample is taken of the liquid as it is being pumped to sea. The samples are analysed at Dounreay and records of the results are held available for inspection by persons authorized by the Secretary of State for Scotland.

Gaseous Effluent

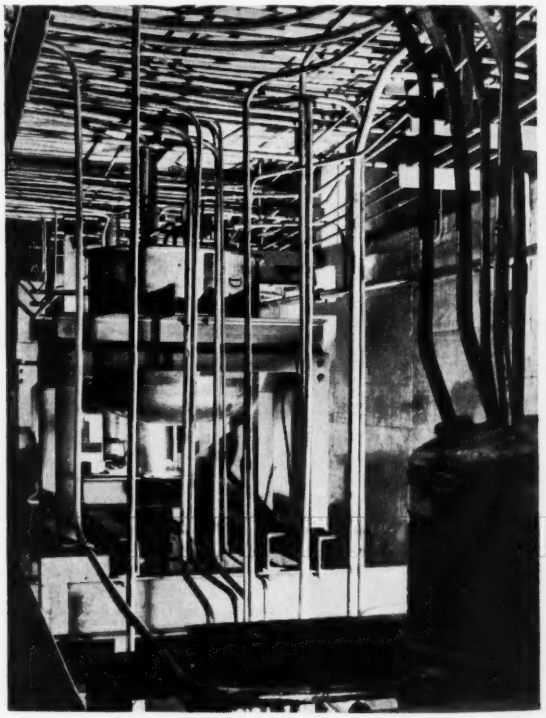
Most buildings are divided into working and plant areas as shown on the sketch on page 289. Fresh air is sucked or blown into the working area then extracted from the plant area. This arrangement ensures that personnel are always working in a fresh air atmosphere, and should a leak develop on the plant side, the direction of flow would ensure that any contamination would be carried away in the extract system.

In certain operations where active dust or gas is produced, all work is carried out in totally enclosed glove boxes. A special extract system removes the contaminated air which is then passed through special filters before going into the main extract system.

The extract from each building is connected to a main duct which runs the full length of the chemical plant and terminates at the fan house and chimney. For normal operation two fans each driven by separate electric motors provide the extraction. In the event of an electrical supply failure a diesel engine automatically cuts in and drives one fan only, thus ensuring continuity of extraction in all cases.

In chemical plants which process irradiated fuel elements, gases and fine particulate matter which may be radioactive are released during decanning, dissolution in chemical reagents, and chemical treatment of solid material.

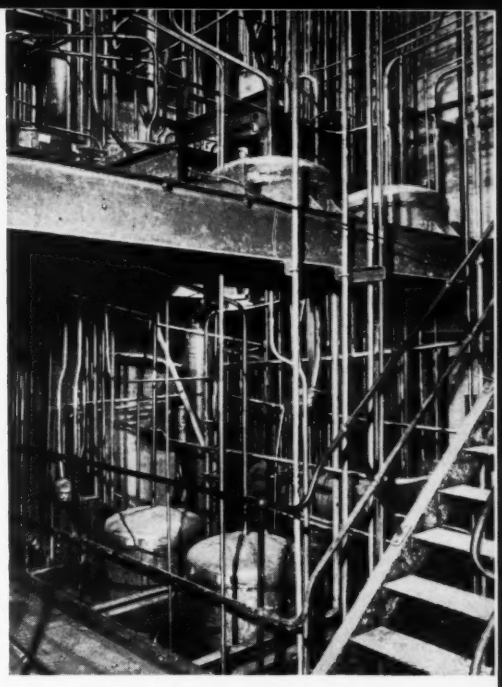
The main effluents are radioactive gases including iodine-^{131}, xenon and krypton; inactive gases such as nitrous fumes, and radioactive particulate matter.



Some of the pipework and vessels in the Highly Active Effluent distillation plant.

All vessels where nitrous fumes are evolved from a radioactive solution present a possible hazard, in the form of entrained radioactive liquor, in addition to the oxides of nitrogen. These vessels are vented through water scrubbing towers, where the nitrous fumes are dissolved and any entrained radioactive liquor is removed, leaving only insoluble inactive gases to be discharged to atmosphere.

Uranium oxide and fluoride are handled in dry powder form. They are beta-active and have long half lives. In order to guard against discharge of particulate matter, all gaseous effluents originating from these materials are filtered through special resin treated merino wool filters, which remove all activity before discharging into the main gaseous effluent system, which has facilities for continuous sampling.



Another view of pipework in the H.A.E. plant.

Fuel Element Examination

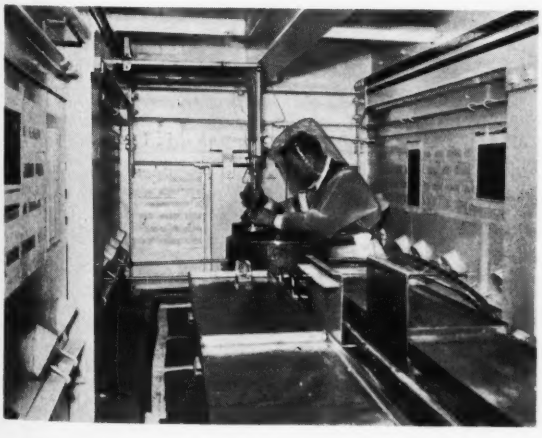
One of the laboratories on which construction is not yet complete is that in which irradiated fuel elements from the fast reactor are to be examined.

The equipment will include manipulators, universal cutting machines, lathe, furnaces, X-ray and density measurement, inspection and material testing machines, optical and TV viewing facilities, and all the associated handling and shielding equipment. The complete laboratory, except for the concrete structure, is being supplied by Pye Ltd. The laboratory is a cave of U-shaped form—a concrete cave with an area of 1,100 sq. ft. with walls 4 ft. 6 in. thick, partly lined with steel. For observation, there are windows at intervals in the walls, composed of glass-walled tanks containing a saturated zinc-bromide solution. At each window, facilities are provided for remote handling of the elements, the manipulators being manufactured by Pye Ltd., by agreement with AMF Atomics, a division of the American Machine and Foundry Company. In conjunction with these, when close examination of the processes inside the cave is necessary, optical periscopes and closed circuit television are used. The bromide tanks were manufactured by J. Evans and Sons (Portsmouth), Ltd.

The cave is divided into ten separate test stations for carrying out the various mechanical, physical and metallurgical operations required, all being remotely controlled, in many cases under water. The following are some of the interesting operations required.

The examination and measurement of the internal and external diameters of the element which requires the use of a ¼-in. periscope viewed by industrial television camera. The de-canning of the element and removal of its sheath requires the use of various cutting machinery culminating in a remotely handled lathe for the preparation of test specifications.

The metallurgical examinations possible include X-ray examination, density measurement, tensile and impact testing, and remote viewing of specimens under the microscope. Provision has been made for the carrying out of heat treatment where necessary.



General view of chemical analysis cell showing remote control equipment being examined by man in maintenance suit.

The Control Laboratory

The responsibilities of the Chemical Group do not, of course, end with the processing of fuel elements and the disposal of effluent. The actual H.Q., as it were, of the Chemical Group is the Control Laboratory where about 100 chemists and physicists are employed.

One of the more interesting features is the arrangement for analysis of highly active materials behind heavy shielding. The remote control mechanism used (illustrated) possesses considerable flexibility in operation. To eliminate the necessity for the tilting of bottles containing specimens for analysis, one of the movements on the remote control mechanism includes a hypodermic needle which can penetrate the rubber bung of the bottle and remove a quantity of its contents by a syringe mechanism. The bottle and its heavy shielding flask can travel up and down the length of the cell by means of a remote operated trolley running on rails at a convenient height. The progress of analysis is watched through high-lead glass windows.

Health Physics Group

The Health Physics and Safety Group is responsible for all aspects of radiation and industrial safety, for the entire establishment. Regular surveys are carried out by Health Physics monitors in all plants and operating areas where radioactive materials are handled, and levels of radiation and of air and surface contamination are measured. Where high external radiation levels occur, working times for personnel in the area will be specified by Health Physics staff.

The Health Physics Group is also responsible for personnel monitoring, by the usual film badges and, when

Fume cupboards in Chemical Services laboratory.

necessary, these may be supplemented by a quartz fibre electrometer (Q.F.E.) which provides an immediate record of the radiation received. Personnel radiation exposure cards are used to record the radiation received by each individual worker.

Health Physics monitors are in attendance during operations involving radioactive hazards, and are available to monitor operators and check for body contamination after completion of their work, and if necessary to provide a personnel decontamination service.

Criticality Control

Dounreay Works will store and process large quantities of fissile material, and indiscriminate accumulation of this material could possibly give rise to a criticality incident. All work involving fissile material is subject to strict regulations designed to ensure that a criticality incident does not occur. The Health Physics Group acts in an inspectorial and advisory capacity to ensure that there is no infringement of these regulations.

Laundry Service

The Works Laundry is operated by the Health Physics Group and washes clothing from all plants on the Works. Contaminated clothing is monitored after laundering, and is reissued if found to be clear of contamination.

Decontamination Service

Portable items of plant and equipment are cleaned in the Decontamination Centre. They are issued for re-use when the surface contamination is reduced to the safe level.

Solid Active Waste Disposal

A collection service for solid active waste is operated by the Group. Combustible waste will be burned in the active

Dounreay

Le réacteur rapide de Dounreay a été décrit dans un article précédent, le présent article décrit quelques unes des autres réalisations de l'établissement.

Le Réacteur d'Essai des Matériaux est du même type que DIDO, l'unité correspondante à l'établissement de Harwell, et on donne une comparaison des facilités expérimentales qui sont disponibles, ainsi qu'une description succincte du programme d'essai.

Un aperçu est donné du cycle de combustible et des méthodes par lesquelles les éléments irradiés sont traités pour enlever les produits de fission et récupérer l'uranium sous forme métallique pour être fabriqués à nouveau en éléments combustibles.

Il y a une description succincte des méthodes pour disposer des produits de rebut. Les liquides qui sont très actifs sont condensés et emmagasinés sous terre, et ceux de faible activité sont déchargés en mer par un " pipeline " placé dans un tunnel.

L'effluent gazeux est traité par filtration pour être certain qu'aucune matière en particules ne soit déchargée. Des schémas montrent le principe général de la ventilation adoptée dans l'ensemble des laboratoires chimiques pour prévenir la libération de toute poussière qui puisse devenir alpha-active. Les rebuts actifs solides sont brûlés s'ils sont combustibles, dans le cas contraire ils sont transférés dans un emplacement spécial d'emmagasinage actif.

On mentionne également les laboratoires principaux de contrôle chimique et le Groupe de Santé Physiques responsables de tous les aspects de protection contre les radiations et la sûreté industrielle.

Dounreay

Der schnelle Reaktor von Dounreay wurde in einem früheren Aufsatz bereits beschrieben; der vorliegende Aufsatz beschreibt einige der weiteren Werke, die zu der Anlage gehören.

Der Reaktor zur Prüfung der Materialien gehört zum selben Typ wie DIDO, dem entsprechenden Werk in den Anlagen von Harwell. Die vorhandenen Möglichkeiten zur Durchführung von Untersuchungen werden verglichen und das Prüfungsprogramm kurz dargelegt.

Der Brennstoff-Kreislauf wird in grossen Zügen gezeigt, und es werden die Methoden dargelegt, nach denen die bestrahlten Patronen behandelt werden, um die Spaltprodukte zu entfernen und das Uran in Form von Metall wieder zu gewinnen, das dann erneut zur Fabrikation von Brennstoff-Patronen dient.

Es wird eine kurze Beschreibung der Methoden gebracht, nach denen man die Abfall-Produkte entfernt. Flüssigkeiten, die hochaktiv sind, werden kondensiert und unter der Erde gelagert, Flüssigkeiten von geringer Aktivität werden durch eine Rohrleitung, die in einem Tunnel verlegt ist, in die See abgeleitet.

Gasförmige Abscheidungen werden einer Filtrierung unterzogen, um sicher zu gehen, dass nicht feste Partikelchen mit abgeführt werden. Diagramme zeigen die prinzipiellen Grundlagen, nach denen die Ventilation in den chemischen Laboratorien überall durchgeführt wurde, um das Entweichen von irgendwelchen Staub zu verhindern, der alpha-aktiv werden könnte. Fester aktiver Abfall wird verbrannt, soweit er brennbar ist, im übrigen sonst in ein spezielles Lagerungsgebiet für aktives Material gebracht.

Ferner werden die hauptsächlichen chemischen Kontroll-Laboratorien erwähnt und die Abteilung für Gesundheits-Physik, die für alle Arten des Schutzes gegen Strahlung und für die industrielle Sicherheit verantwortlich ist.

Dounreay

El reactor rápido de Dounreay fué descrito en un artículo anterior, y este artículo describe algunas de las otras características del establecimiento.

El reactor de ensayar materiales es del mismo tipo que DIDO, la unidad correspondiente en el establecimiento de Harwell, y se ofrece una comparación de las facilidades experimentales que hay disponibles, así como una breve reseña del programa de ensayos.

Se ofrece una reseña del ciclo de combustible y de los métodos mediante los cuales los elementos irradiados son tratados para remover los productos de fisión y la recuperación de uranio en forma metálica para ser refabricado en elementos de combustible.

Hay una breve descripción de los métodos para deshacerse de productos desperdiciados. Los líquidos que son altamente activos son condensados y almacenados bajo tierra, y aquellos de baja actividad son descargados en el mar por medio de un conducto en un túnel.

El efluente gaseoso es tratado por medio de filtración para asegurar de que no se descargue ninguna materia particulada. Los diagramas muestran los principios generales de ventilación adoptados en todos los laboratorios químicos para impedir la liberación de cualquier polvo que pudiera volverse alfa-activo. Los desperdicios sólidos activos se queman si son combustibles. De otra manera, se transfieren a una zona especial de almacenamiento de materias activas.

También se hace mención de los principales laboratorios químicos de control y del Grupo de Física de Salud que es responsable de todos los aspectos de protección contra la radiación y de la seguridad industrial.

waste incinerator and non-combustible waste will be stored in a special active storage area.

Industrial Safety

The safety section is responsible for ensuring that the Factories Acts and any other statutory requirements are implemented, in addition to advising on all aspects of industrial safety. This section is also responsible for accident prevention and investigation and the compilation of accident statistics. The safety section supplies and maintains all protective clothing and equipment used on the Works. In the event of operations requiring the use of pressurized suits for protection of operators against heavy radioactive contamination this section provides the necessary services.

The Fire Brigade, which also provides an ambulance and first aid equipment, is part of this section. Great care has been taken to ensure a high standard of industrial safety from all aspects.

Stainless steel vessels in reagent mixing room.

List of Contractors

ACALOR (1948), LTD., Kelvin Way, Crawley, Sussex
Acid-resisting flooring for laboratories.

ACCLES AND POLLOCK, LTD., Oldbury, Birmingham
Stainless steel tubing.

ALUMINIUM PLANT AND VESSEL CO., LTD., Manor Royal, Crawley, Sussex
M.J.R. Reactor vessel.

DANIEL ADAMSON AND CO., LTD., Dukinfield
Boiler plant, oil-burning equipment.

ANDREW MACHINE CONSTRUCTION CO., LTD., Turncroft Lane, Stockport
Ducting, main extraction fans and ventilation equipment for M.T.R.

ASHMORE, BENSON, PEASE AND CO., Parkfield Works, Stockton-on-Tees
Gasholders.

BROOK MOTORS, LTD., Empress Works, Huddersfield
Electric motors.

GEO. W. BRUCE, LTD., 106 Crown St., Aberdeen
Precast floors and roofs.

BRUCE PEEBLES, LTD., Edinburgh
Alternators.

BRUSH ELECTRICAL ENGINEERING CO., LTD., Loughborough
Motor alternator frequency changer.

BUTTER BROS. AND CO., LTD., Glasgow, S.1.
Electric cranes for Diesel generating house.

CAPE ASBESTOS CO., LTD., 144 Park Street, London, W.1.
"Rocksil" insulation.

CUTROCK ENGINEERING CO., LTD., Dollis Park, London, N.3.
Section-cutting machines.

CROSSLEY BROS., LTD., Openshaw, Manchester, 11.
Diesel generating plant.

DARLINGTON INSULATION CO., LTD., 38 Great North Road, Newcastle upon Tyne
Thermal and acoustic lining to DMTR.

J. EVANS AND SON (PORTSMOUTH), LTD., Marcyn Works, Goldsmith Avenue, Portsmouth
Zinc bromide viewing tanks.

EVERSHED AND VIGNOLES, LTD., Acton Lane Works, London, W.4.
Instruments.

EKCO ELECTRONICS, LTD., Southend
Main instrument panel for DMTR.

ALEX FINDLAY AND CO., LTD., Motherwell, Lanarkshire
Structural steelwork.

GENERAL ELECTRIC CO., LTD., Magnet House, Kingsway, London, W.C.2.
Electric furnaces.

G.W.B. FURNACES, LTD., Dibdale Works, Dudley, Worcs.
Electric furnaces for metallurgical work.

MATTHEW HALL, LTD., 26 Dorset Square, London, N.W.1.
Steam main, compressed air main and condensate runs. Heating, hot water supplies, mechanical ventilation, steam systems.

H. HARGREAVES AND SONS, LTD., Cook Street, Bury, Lancs.
Ventilation ducting.

HAYWARD, TYLER AND CO., LTD., Luton, Beds.
M.T.R. main heavy-water circulating pumps.

HEAD WRIGHTSON (TEESDALE), LTD., London, E.C.1.
Internal erection of M.T.R. cooling towers.

HEAD WRIGHTSON PROCESSES, LTD., London, E.C.1.
Main contractors for M.T.R.

HONEYWELL BROWN, LTD., Wadsworth Road, Perivale, Middx.
Instruments.

INTERNATIONAL COMBUSTION (NUCLEAR APPLICATIONS), LTD., Derby
Transit flasks.

KEIGHLEY LIFTS, LTD., Keighley
Goods lifts for M.T.R.

GEORGE KENT AND CO., LTD., Luton, Beds.
Instruments.

LAURENCE SCOTT AND ELECTROMOTORS, LTD., Gothic Works, Norwich
Motor alternator equipment.

METALASTIK, LTD., Evington Valley Road, Leicester
Anti-vibration mountings for Diesel engines.

METROPOLITAN-VICKERS ELECTRICAL CO., LTD., Manchester, 17.
Mass spectrometer and h.f. heating equipment.

MITCHELL ENGINEERING CO., LTD., Bedford Square, London, W.C.1.
Equipment for fuel-element viewing laboratory.

MOTHERWELL BRIDGE AND ENGINEERING CO., LTD., Motherwell, Lanarkshire
M.T.R. air-tight building.

NORTHEY ROTARY COMPRESSORS, LTD., Alder Road, Parkstone, Dorset
Helium blowers for DMTR.

PATERSON HUGHES ENGINEERING CO., LTD., Glasgow, N.W.
30-ton overhead crane.

PHILIPS ELECTRICAL, LTD., Shaftesbury Avenue, London. W.C.2.
X-ray gear.

POWER GAS CORPORATION, LTD., Stockton-on-Tees
Dust extraction, washing and drying plant.

PYE, LTD., Cambridge
Slave manipulators. Main contractors for fuel-element examination laboratories.

A. REYROLLE AND CO., LTD., Hebburn, Newcastle upon Tyne
Main switchgear for complete distribution scheme.

RUBEROID, LTD., 1 New Oxford Street, London, W.C.1.
Steel roof decking and bituminous felt roofing.

SAVAGE AND PARSONS, LTD., Watford By-pass, Watford, Herts. (in connection with Pye, Ltd.)
Slave manipulators. Shield plugs for DMTR.

SCOTTISH TARMACADAM AND ASPHALT CO., LTD., 44 Bilbao, Glasgow, C.5.
Security fencing.

JAS. SCOTT AND CO. (ELECTRICAL ENGINEERS), LTD., 175 St. Vincent Street, Glasgow, C.2.
Main electrical contractors.

SIMMONDS AEROCESSORIES, LTD., Treforest, Pontypridd, Glamorgan
Control-rod position indicators.

TALBOT STEAD TUBE CO., LTD., Walsall, Staffs.
Stainless steel tube, pressings, and fabrication.

WILLIAM TAWSE, LTD., Angusfield, Aberdeen
Site works and drainage; Thurso staff housing; Tarmacadam roads.

TAYLOR WOODROW (BUILDING EXPORTS), LTD., Ruislip Road, Southall, Middx.
Arcon building for criticality laboratory.

T.I. PLASTICS, LTD., Stoke-on-Trent
Polythene tubing.

P. M. WALKER AND CO. (HALIFAX), LTD., Alexandra Works, Halifax
Dust extraction plant and high-efficiency cyclone collectors.

T. W. WARD, LTD., Albion Works, Sheffield
Main contractors for stainless-steel tanks and pipework gear in highly active effluent plant. Chemical separation plant. Graphite laying.

WHARTON CRANE AND HOIST CO., LTD., Reddish, Stockport
Two 25-ton cranes.

WHATLINGS, LTD., 10 Woodside Crescent, Glasgow, C.3.
Main buildings and civil engineering work.

Technical Papers and Publications

The Scaling-Up Symposium

THE development of a chemical process from the laboratory to the stage of commercial production is seldom a simple matter, and one might say that the recent Joint Symposium on the "Scaling-up of Chemical Plant and Processes" has itself been responsible for a considerable scaling-up in the availability of information on the subject. Held under the auspices of Het Koninklijk Instituut Van Ingenieurs (Chemical Engineering Group), De Koninklijke Nederlandse Chemische Vereniging (Section for Chemical Technology), the Society of Chemical Industry (Chemical Engineering Group) and the Institution of Chemical Engineers, the conference presented 13 papers dealing with a very wide range of problems encountered. It was officially opened, in Dutch and English, by Mr. E. Le Q. Herbert, managing director of the Shell Marketing and Refining Co., Ltd.

Introduction

An introductory paper, by Mr. R. Edgeworth Johnstone and Prof. M. W. Thring, pointed out that unexpected effects could occur not only in the translation from laboratory to pilot plant, but in the further stepping up from pilot plant to full-scale production, due to unexpected physical or chemical effects attending the change of scale. It was not always realized that there could be "reverse-scale" effects so that a process can be successful in laboratory and large-scale plants, yet inoperative in the pilot stage, and it was interesting to speculate on the number of potentially valuable processes that had been abandoned at the pilot stage for this reason.

Scale effects could sometimes be so large and incalculable that accurate prediction from a model would not be possible and the only safe method would involve a series of pilot plants of gradually increasing size—a slow and expensive procedure. Alternatively scale effects might not occur at all; there had been cases where the pilot plant had been omitted.

The basic principle governing the effects of change of scale was Newton's Principle of Similarity, first practically applied in the field of hydrodynamics by Froude and by Reynolds. Similarity principles had first been applied to geometrically similar systems to correlate the performance of liquid mixers, which was not yet amenable to exact mathematical analysis. In its simplest form the principle of similarity attempted to represent a physical or chemical process by a relation between several dimensionless groups, one of which contained the unknown variable. If the groups containing the known variables were made to have the same value on both small and large scale the group containing the unknown variable would have the same value. Geometrical similarity did not, however, require the small apparatus to be an exact miniature of the large, it could be attained by a complete scale model, a full-sized element, or a model element. It was not, incidentally, essential that a model, or model element be regular; it could be distorted to give different scale ratios along different co-ordinates without destroying geometrical similarity.

A preferable method was to derive the appropriate dimensionless groups from the fundamental differential equations.

One of the most important factors was, of course, the "regime" or rate-determining factor; which could usually be classified into three types; dynamic, thermal, or chemical. It was important not to confuse the prevailing regime with the nature of the process. Heat transfer by forced convection, although a thermal process, was classified as dynamic, because heat transfer rate was a function of fluid velocity. Natural convection, in which temperature difference was the determining factor, was a thermal process, subject to a thermal regime. The prevailing regimes could be further subdivided as follows:—

Dynamic regimes into those controlled by gravity, viscosity or surface tension.

Thermal regimes into those controlled by conduction, convection and radiation.

Chemical regimes into homogeneous and heterogeneous, the latter being further subdivided into those having a fixed (solid-fluid) or a mobile (fluid-fluid) interface.

It was, of course, possible to have two or more rate-determining processes, scaling up under different laws. This constituted a "mixed" regime.

Fission Product Removal

Some of the difficulties faced by nuclear process designers could be gathered from Mr. Warner's paper. In the first place, the plant was required simultaneously with the first reactors it had to serve and, in consequence, it was not possible to utilize a pilot plant; it was necessary to scale-up direct from the laboratory. An additional difficulty, in conjunction with the Windscale columns, was that the design estimates had to be reliable, on account of the heavy shielding required.

The development of the solvent extraction processes on a laboratory scale has resulted in a number of different techniques, including the micro-airlift and the mini-mixer. Full-scale apparatus usually took the form of packed columns or mixer-settler equipment. **[The liquid-liquid extraction process has already been described in *Nuclear Engineering* for July and August, 1956.**—ED.]

A packed column has, of course, two important dimensions—the height, which is determined by the number of theoretical stages required by the process, and the cross-sectional area required for the design throughput. Both of these dimensions were, of course, interdependent and both were also affected by the type of packing used.

The general impression derived from the paper was that the scaling-up of packed columns for fission product extraction was not at first found to be an easy process but that considerable progress had taken place. Mixer-settlers, on the other hand, had proved more amenable—there was a comparatively simple approach to the mixer on the basis of energy input.

One important point made by the author was the importance of thermal effects—these could pass almost unnoticed on a small-scale model but had quite considerable effects upon the full-scale performance.

PAPERS PRESENTED

Introductory Paper. By **R. Edgeworth Johnstone,** M.Sc., F.R.I.C. (Assistant Director of Ordnance Factories, M.o.S.) and **Prof. M. W. Thring,** M.A. (Professor of Fuel Technology and Chemical Engineering University of Sheffield).

"The Scaling-up of Reactors from a Knowledge of Kinetics." By **K. G. Denbigh,** D.Sc., M.I.Chem.E. (Professor of Chemical Technology, Edinburgh).

"The Economic Aspects of Scaling-up Chemical Plants." By **R. G. Dickerson** (The Distillers Co. Ltd.).

"Influence of Design Variables on Capacity and Efficiency of Rotating Disc Contactors." By **Dr. G. H. Reman** (Koninklijke Shell-Laboratorium, Amsterdam).

"Problems Encountered in Stirred Slurry Reactors." By **Dr. Ir. J. G. van de Vusse** (Koninklijke Shell-Laboratorium, Amsterdam).

"Model Tests with Cyclones." By **A. L. de Gelder,** M.Sc. (Staatsmijnen in Limburg, Central Laboratory, Geleen).

"The Scaling-up of Solvent Extraction Processes for Irradiated Nuclear Fuels." By **B. F. Warner,** B.Sc., A.R.I.C. (R. and D. branch, U.K.A.E.A., Windscale).

"The Performance of Technical Apparatus for Gas Absorption." By **P. J. Hoftyzer,** A.M.I.Chem.E. (Central Laboratory Staatsmijnen, The Netherlands).

"Scale-up Experience in the Removal of Hydrogen Sulphide from Exhaust Gases from a Viscose Factory." By **M. J. Hagger,** B.Sc., A.M.I.Chem.E.; **E. A. Jones,** B.Sc., and **D. C. F. Pratt,** A.C.G.I., A.M.I.Chem.E. (Chemical Engineering Section, Courtaulds Ltd., Coventry).

"The Effect of Scale on Air-separation Plant Design." By **P. M. Schuftan,** Dr. Phil., and **J. Forrest,** B.Sc., A.M.I.Mech.E. (British Oxygen Engineering Ltd., Edmonton).

"Experiments with Furnace Models." By **N. P. Bacon,** B.Eng., Ph.D., A.M.Inst.F. (United Steel Companies Ltd.).

"The Development of a New Process (Autofining) for the Catalytic Desulphurization of Petroleum Distillates." By **F. W. B. Porter,** B.Sc., F.Inst.Pet., and **C. V. Rollinson,** B.Sc. (British Petroleum Co. Ltd.).

"Scale-up Methods for Continuous Filtration Equipment." By **D. A. Dahlstrom,** B.Sc., Ch.E., Ph.D. (The Eimco Corporation, Illinois), and **D. B. Purchas,** B.Sc. (L. H. Manderstam and Partners).

WORLD POWER CONFERENCE

Economic Factors Affecting the Establishment of Nuclear Power in Under-developed Countries. By J. A. Jukes, M.A., B.Sc.(Econ.), *Economic Adviser to the U.K.A.E.A.*

Capital costs per installed kW vary considerably from country to country but in general, for coal-fired stations, are between £50 and £65 in countries which manufacture their own equipment. For under-developed countries the cost will be higher both because of transport costs and the costs of employing skilled engineers to erect them. Capital costs of hydro-electric schemes also vary from country to country; but for comparison it might be reasonable to take a figure of about £90 to £110 per kW, i.e. something above the cost of coal and oil-fired stations but below the current cost of nuclear stations.

The length of life at present assumed for a steam generating station of between 20 and 30 years is unlikely to vary much in the future.

For hydro-electric power stations, cost of fuel is negligible. The price of oil for many under-developed countries, especially those in the Middle East is low; for others, transport costs vary considerably. The price of coal also varies greatly from area to area, being as low as 7s. a ton on the South African Rand and as high as £7 a ton in Western Europe. The price of coal may be expected to rise continuously in relation to other costs. With the increasing difficulty of extraction, a relative annual rise of about 1% is a reasonable assumption.

Thermal efficiencies of 34-35% are becoming common for large up-to-date steam generating stations, and higher efficiencies are being achieved in certain cases. This rise will probably continue for some time though the indications are that the technical limits are being approached.

Operating costs vary with conditions. For modern coal-fired stations costs as low as 0.05 d/kWh can be achieved.

The capital cost of nuclear power stations is dependent not only on the design chosen but on a number of factors, such as site conditions, costs of construction in different areas, etc. For the first gas-cooled graphite-moderated natural uranium power stations now being built for the U.K.'s Electricity Authorities, the capital cost will be about £130 to £140 per kW sent out. These costs will gradually come down, and may be perhaps 15% lower for the second group of stations for which contracts will be signed in about 18 months time. The figures above are for 300 MW stations. The capital costs of a 50 MW reactor of the natural uranium type might be 50% higher, say £200 per kW.

There is no reason to doubt the assumption now being made, that a plant should last at least 20 years. In the case of a 300 MW station with two gas-cooled graphite - moderated natural uranium reactors, the initial fuel charge might be 500 tons at about £15,000 to £20,000 a ton. Enriched fuel would cost more but would permit the use of a reactor system with a lower neutron economy and a higher heat output per ton.

At the present time it is expected that the fuel elements for the first nuclear power stations in the U.K. will remain in the reactors until 3,000 MWd of heat have been produced in each ton of natural uranium. With stronger fuel elements and enriched fuel, a considerably higher irradiation level before reprocessing should be possible. As reactor temperatures rise thermal efficiency should rise from 27% to at least 35% or 40%.

For economic operation with the gas-cooled graphite - moderated natural uranium reactor a fuel-processing plant must have an annual throughput of well over 1,000 tons. Since a 300 MW reactor only needs about 100 tons of fuel each year for replacement purposes it will be seen that until a country has developed a comparatively large programme it will be much cheaper to make use of overseas facilities for reprocessing.

Small Reactors

Much development work must still be done on the smaller reactor systems, and before under-developed countries will wish to incorporate them as part of their power programme they must be proved not only competitive with conventional power stations but also fully reliable in performance. This stage will probably be reached in the medium power range before it is reached by smaller systems; in both cases, however, a considerable programme of research and development is required. This will cover not only the initial work but also the design and construction of the prototype of a commercial reactor, the successful operation of that prototype and the construction and successful operation over a period of a commercial version of the reactor. For this to be done a period of at least 10 years must ensue.

It may, however, be worthwhile to assess the possible economics of a smaller reactor system in 10 years time in order to show in what circumstances it might best compete with conventional systems in less developed countries. The figures have been given at load factors of 75% (about the maximum possible) and at 25% (which is about the minimum at which one would expect a station with a high capital cost ever to operate).

Table 1.—Comparison of Generating Costs (Based on assumptions in Table 2)

	Pence/kWh s.o.		
	Nuclear	Coal	Diesel
Capital charges ..	0.40	0.13	0.09
Initial fuel charge ..	0.05	—	—
Works costs	0.05	0.05	0.04
Fuel costs	0.22	0.42	0.74
Gross generating costs	0.72	0.60	0.87
Less plutonium credit	0.06	—	—
Net generating costs..	0.66	0.60	0.87

Table 2.—Performance Assumptions

	Nuclear	Coal	Diesel
Output	300 MW s.o.	200 MW s.o.	10 MW s.o.
Capital cost/kW s.o.	£135	£55	£36
Thermal efficiency	27%	34%	—%
Load factor ..	75%	75%	75%
Life of plant ..	20 yr.	27½ yr.	25 yr.
Rate of interest	5%	5%	5%
Initial fuel charge	500 tons	—	—
Irradiation level	3000 MWD/T	—	—
Cost of fuel/ton	£18,000	£4.3.0	£12.10.0
Plutonium credit	£4.6.0 per g p	urified	metal

Table 3.—Cost of Electricity from a Small Nuclear Power Station

Capacity Load Factor	pence per kWh (s.o.)	
	10 MW	20 MW
75%	1.29	0.95
25%	2.31	2.05

These figures are, it must be stressed, purely illustrative and do not relate to any one particular system.

B.E.P.C.

Nuclear Energy in Great Britain. By J. C. Duckworth, B.A., F.Inst.P., A.M.I.E.E., and W. H. C. Pilling, B.A., M.I.E.E.

AFTER summarizing the British programme, an account is given of probable economics. Prominent amongst running expenses is fuel costs.

Even with fixed plutonium prices actual computation of fuel costs is not entirely a straightforward matter, since there is not a simple instantaneous throughput as in the case of coal. The original fuel is, in effect, a capital charge, and, during an assumed twenty year life of the reactor, is changed on the average about four times. At the end of its life, the reactor contains its full complement of fuel which has value mainly because of its plutonium content. It has, therefore, been decided to calculate the fuel costs in three parts:—

(i) Interest on the initial capital investment in fuel.
(ii) A sinking fund to cover the difference in value between the initial and final fuel complements.
(iii) The cost of fuel replaced.

The first two of these are capital charges and account for about one third of the total fuel cost. The fuel cost for determining "order of merit" of the station in the system is, therefore, strictly only the last of the three. Average costs over the life of the plant are worked out by this method, but the "actual" cost of fuel per unit sent out will vary over the life, particularly before the equilibrium state is established.

Centrepiece of the Brussels World Fair next year will be the "Atomium"—a 350-ft-high structure representing an elementary steel crystal. Of the nine spheres five will be exhibition halls. The central column will contain an elevator.

"Skate," the first U.S. production-model nuclear submarine was launched at Connecticut on May 16 by the Electric Boat Division of General Dynamics Corporation. The 265-ft 2,400-ton vessel was christened by Mrs. Lewis L. Strauss, wife of the chairman of the U.S.A.E.C.

World News

International

More than 200 delegates from 21 Latin-American nations and the United States attended a five-day symposium at Brookhaven National Laboratory in May. Dr. Milton S. Eisenhower, representing President Eisenhower, said that the greatest obstacle to progress in the peaceful application of nuclear energy is lack of manpower. Although the student training resources of the United States were already strained it was prepared to share them with friendly countries.

A three-day conference on peaceful uses of atomic energy was held in Tokyo last month under the sponsorship of the Japanese and American atomic industrial forums. The American delegation of 76 included representatives of leading nuclear plant manufacturers. Seventy observers from other Pacific countries, including Australia, were also present. The most important feature of the current American reactor sales campaign in Japan seems to be denigration of the Calder Hall type of reactor, judging by the remarks made by Mr. Kenneth Davis, assistant director, Reactor Development Division, U.S.A.E.C.

Britain and the United States have reached further agreement on an exchange of information on the peaceful uses of atomic energy. Sir Edwin Plowden, chairman, U.K.A.E.A., arrived home on June 6 after talks with Mr. Lewis Strauss, chairman, U.S.A.E.C. The agreement provides for an exchange of information on the Calder Hall and various American experimental reactors in addition to "other areas of co-operation between the two countries."

Information on nuclear-powered submarines is being exchanged by the U.S. and the U.K. On May 27 three representatives of the U.S. Navy and the A.E.C., Rear-Admiral H. G. Rickover, Rear-Admiral A. M. Morgan and Mr. I. H. Mandril visited Britain. Discussions took place with Rear-Admiral G. A. M. Wilson who is in charge of U.K. naval and civil nuclear propulsion on behalf of the Admiralty, and Dr. J. V. Dunworth, head of the Reactor Division, A.E.R.E.

Economic committee of the Baghdad Pact on May 18 adopted a resolution aimed at the introduction of nuclear training in the area. The committee resolved that a training centre should be established in Baghdad. Non-recurring expenditures will be met by Britain; recurring costs will be paid by the four Middle East members, Persia, Iraq, Pakistan and Turkey.

Problems of European co-operation in nuclear research and power production were discussed at a meeting of the United Kingdom Council of the European Movement in London on May 22. Mr. Campbell Secord, an adviser to Euratom, said that if the U.K. joined more closely with the Euratom countries it could play not only a leading part, but a part of great value to the country.

United Kingdom

Tenders for a further two 500 MW nuclear power stations will be sought by Central Electricity Authority within the next few months. Contracts will be signed early in 1958. The probable sites are Blaenau Festiniog, Merionethshire, North Wales, and Dungeness on the Kent coast.

The siting of the Welsh station is interesting because it will probably be adjacent to the 300 MW pumped-storage scheme already under construction. During off-peak periods of demand the electricity generated will be used to pump water to a storage reservoir. At peak demand the water will drive generators; the overall loss of power is expected to be about 25%.

A Safety Branch has been formed by A.E.A. to supervise the Authority's responsibilities for control of safety under the 1954 Act. The new branch comprises safety executive and health advisory committees. The first is essentially concerned with problems of designing, siting and operating reactors and process plant. It has two sub-committees—one dealing specifically with reactor safety, the other with safety at ancillary establishments. The health advisory committee considers the effects of radiation on public health, and inaugurates

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The new London headquarters for the Atomic Energy Authority are being built by Trollope and Colls Ltd., at the corner of Charles II Street and Lower Regent Street. The premises will not be ready for occupation until early next year.

During the State visit to Denmark in May, H.M. The Queen met the eminent Danish nuclear physicist, Professor Niels Bohr who lives in a "grace and favour" residence adjoining the Carlsberg Breweries.

research into radiation hazards. Mr. F. R. Farmer has been appointed chief safety officer in charge of the Safety Branch.

Construction work on the new research establishment at Winfrith Heath, Dorset, will probably start in the late summer or autumn, Mr. Maudling, Paymaster-General announced during a debate on the Winfrith Heath Bill which extinguishes commoner's rights on the heath.

Africa

U.K.A.E.A. has made available about £10,000 worth of geological equipment to the survey departments of three territories in the Rhodesian Federation. Each territory can borrow a specially equipped Land Rover fitted with radioactive detection gear.

China

Heavy-water reactor of 7 MW output—built with Soviet assistance—is scheduled for completion this year, according to Peking radio. A 25 MeV cyclotron is also being constructed.

Canada

Judging by a statement attributed to Mr. Ian F. McRae, vice president of the Canadian General Electric Co., the 20 MW reactor in course of construction at Chalk River will not now be completed. On June 6 Mr. McRae told the Canadian Manufacturers Association that plans had been changed because of "new technological developments which solve many problems in the design and operation of large power units."

The intention now is to build a smaller reactor as an actual prototype of a 200 MW power reactor.

New uranium mine at Bancroft, Ontario, was officially opened by Ontario Premier Mr. Leslie Frost on May 30. The mine, owned by Faraday Uranium Mines Ltd., has a contract with the Government to supply $30 million worth of ore: output is 1,000 tons per day.

Germany

Nuclear power for ships was discussed by 400 delegates at a two-day international congress in Hamburg, West Germany, early in June. The congress—at which the United States, Britain, Japan, Sweden, West Germany and other countries were represented—was arranged by a West German organization, the Association for the Study and Application of Nuclear Energy to Ship Propulsion and Shipbuilding. Professor Erich Bagge said that the four West German Federal States with a coastline had ordered two land-based reactors to determine the suitability of nuclear power for ships.

Bavarian State Government agreed on June 14, to the construction of a 15 MW nuclear power station at Kahl on the river Main. The station—supplied by Mitchell-A.M.F.—will be built by Rheinisch-Westfälische Elektrizitaets-Werke (RWE).

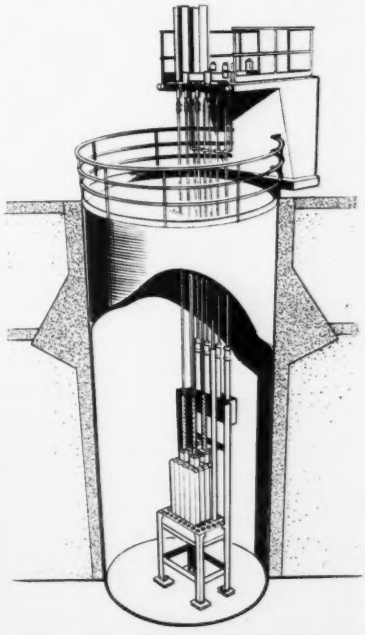
India

Fifty per cent increase in the budget for nuclear energy development has been announced by the Union Finance Minister, Mr. T. T. Krishnamachari. The expenditure envisaged for 1957-58 is Rs. 3.1 crores, as against Rs. 2 crores last year.

In addition to Apsara, the swimming pool reactor and the Canadian gift reactor, it is proposed to set up a zero energy reactor, Zerlina, to study reactor design features. Fuel will be natural uranium; heavy water will be obtained from the U.S. later this year.

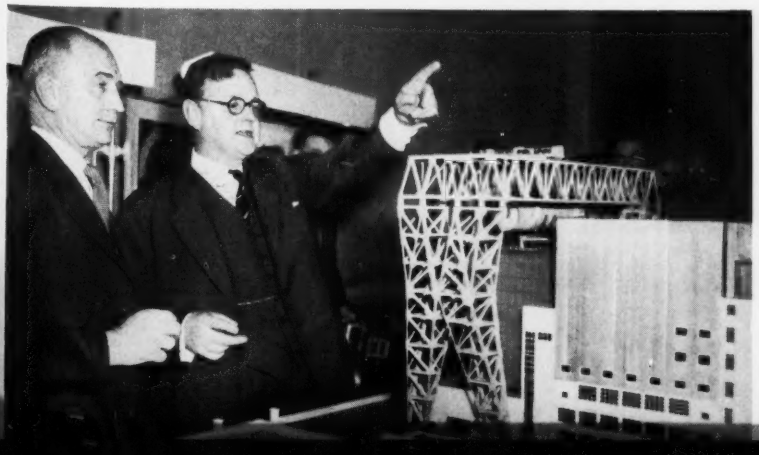
The Finance Minister has also made provision of Rs. 20 lakhs for various new projects including the production of reactor grade graphite, zirconium and processing low-grade uranium ore.

Opening a three-day conference of research workers on genetics and breeding as applied to improvements of plants and animals,

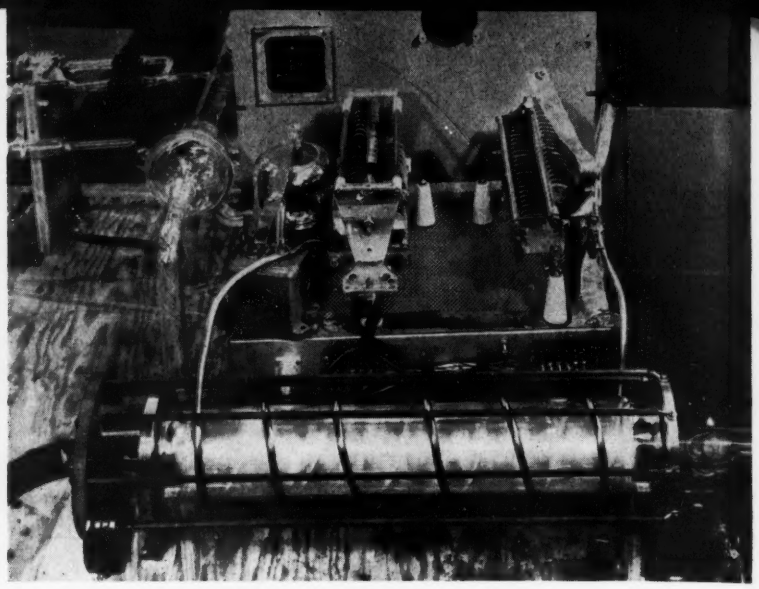


Artists impression of the 10 kW swimming pool reactor which can be seen at Het Atoom, the International Atomic Exhibition at Amsterdam.

Lord Hailsham, Minister of Education, looking at a model of the Bradwell, Essex, nuclear power station (Nuclear Power Plant Co., Ltd.) after he had opened the new Electric Power Gallery at the Science Museum, South Kensington.



Reactor core of the aeroplane reactor experiment at Oak Ridge National Laboratory which Union Carbide Nuclear Company operates on behalf of the A.E.C. Fuel : Enriched uranium tetrafluoride concentrate.



The Stellarator to be built for U.S.A.E.C. at Princeton University will resemble this prototype of an earlier "pinch-effect" device called Columbus. It was developed for controlled thermonuclear research at Los Alamos laboratory.

Mr. A. P. Jain, Union Minister for Food and Agriculture, said that cobalt-60 gamma radiation sources for mutation research would be set up at the Agricultural Research Institute in Bombay and at the Jute Research Institute.

Italy

A Mission of the International Bank for Reconstruction and Development visited Italy to study the financing of the Italian programme for nuclear development.

Experimental CP 5 reactor to be set up at Varese is expected to be operating by 1958. Total cost for the purchase and construction is approx. three milliard lire.

FIAT have applied for permission to prospect for radioactive minerals in the area West of Turin.

Japan

Following the American-Japanese Atomic Power Conference, American manufacturers have offered to supply large-scale reactors. General Electric will build a R6 186 MW Dresden-type (boiling water) reactor for a total cost of $81 million of which just less than half would be for the actual reactor and generator. Westinghouse Electric Corporation has proposed a 134 MW Yankee-type (pressurized water) reactor with total construction costs of $61.8 million.

Nine Japanese electricity supply companies have banded together to form the Federation of Electric Industries. The group will purchase and operate power reactors using either enriched or natural uranium.

Netherlands

The 10 kW swimming pool research reactor supplied by the American Machine and Foundry Company to the Dutch Government under President Eisenhower's "Atoms for Peace Programme" became critical at the end of May. This reactor, constructed in co-operation with Dutch industrial organizations operates with 20% enriched uranium fuel supplied from the United States. From July 1 to September 16, it will be the centre of interest at Het Atoom, the International Atomic Exhibition at Schiphol airport.

Among the other exhibits will be a model of a 20 MW nuclear power station designed and constructed by the Anglo-American team of Mitchell Engineering Ltd. and A.M.F. Atomics Inc. Recently the group secured an order for a similar station from West Germany.

New Zealand

Nuclear research will be assisted by the purchase of a high energy accelerator. Mr Algie, Minister in Charge of Scientific and Industrial Research, said the Cabinet had decided to spend up to £500,000 on atomic research.

Norway

Norway will purchase 16 tons of heavy water from U.S.A. and 8 tons of natural uranium fuel elements from the U.K. When the industrial reactor at Halden, south of Oslo, diverges at the end of this year it will supply local pulp factories with 10,000 tons of steam daily—an increase of about 25% on the average Norwegian daily consumption of steam.

Treaty calling for peaceful nuclear collaboration between Norway and the U.S. ratified on June 10.

South Korea

Uranium ore has been discovered in the area of Kosung, 25 miles north of the 38th parallel on the East Korean coast.

U.S.A.

Treaty ratifying U.S. participation in the proposed 80-nation international atomic energy agency was approved by the Senate foreign relations committee on June 13. The committee attached to its resolution an "interpretation and understanding" stating specifically that the U.S. would withdraw from the organization if any amendment is adopted to its statute which the Senate does not approve.

Four major steps to increase the dissemination of information by the A.E.C. include de-classification of a large number of documents relating to nuclear power production; the admission of foreign nationals to the isotopes course at Oak Ridge Institute of Nuclear Studies; establishment of a Spanish-language nuclear training centre at the University of Puerto Rico, and an Asian nuclear centre in the Philippines.

A Convergatron—a neutron amplifier that would enable a sub-critical mass of uranium fuel to be used in a reactor—was described by Dr. Lyle Borst, chairman of the Physics Department, New York University, before a recent meeting of the American Physical Society.

A.E.C. has asked Congress for a further $5 million to buy facilities for thermonuclear research. The Commission is budgeting for $21.7 million for thermonuclear research this year.

Responding to the A.E.C. offer of assistance for nuclear power plants using design concepts embodied in the FNPG reactor, Florida Nuclear Power Group proposes a water-moderated, natural uranium, gas-cooled reactor. Northern States Power Co. of Minneapolis, propose a boiling-water reactor fuelled with slightly enriched uranium and having large-volume controlled recirculation of the water coolant moderator.

Details of an aircraft reactor experiment were given by Dr. A. M. Weinberg at the Inter-American Symposium on the Peaceful Uses of Atomic Energy at Brookhaven National Laboratory in May. Although designed for 1.5 MW the reactor ran at 2.5 MW. Fuel was enriched uranium tetrafluoride. The reactor—which first became critical in November, 1954—was 3 ft. high and 33 in. in diameter.

Yugoslavia

Belgrade staged the 1957 Sectional Meeting of the World Power Conference from June 5 to 11. Delegates from some 50 nations discussed power, including, of course, nuclear energy, as a factor in the evolution of under-developed countries. Introducing the general report Janez Stanovnik, deputy director of the Yugoslav Institute for International Politics and Economy, said that in many under-developed countries it would be very difficult to improve power resources without foreign assistance. Because energy projects were not always good business propositions there was need for a new non-commercial institution within United Nations to give financial aid for the development of national power systems.

Personal

The Queen's Birthday Honours

Knights Bachelor

F. Pickering, chairman, English Steel Corporation, Ltd., Sheffield.
E. W. Thompson, chairman, John Thompson Ltd., Wolverhampton.

F. Pickering.

E. W. Thompson.

C.B.E.

H. W. Grimmitt, chief engineering inspector, Ministry of Power.
F. Marshall, chairman and managing director, Thos. Marshall and Son, Ltd., Leeds.
E. Player, managing director, Birmid Industries, Ltd.
D. G. Sopwith, director mechanical engineering research, Dept. of Scientific and Industrial Research.
C. M. Vignoles, managing director, Shell-Mex and B.P., Ltd.
J. Walker, chairman, Electricity Board for N. Ireland.

O.B.E.

Lt.-Col. A. C. Newman, V.C., director, W. and C. French Ltd., civil engineering and public works contractors, Essex.
F. A. Rawlings, financial officer, Central Electricity Authority.
J. T. Tomblin, superintendent, Planning Trials Division, A.W.R.E. Aldermaston.
G. Weston, technical director, British Standards Institution.
E. Whitworth, deputy research manager, Nobel Division, I.C.I. Ltd.
A. Wragg, manager, Shell Dept., and chief metallurgist, Vickers-Armstrongs (Eng.), Ltd., Newcastle upon Tyne.
S. J. Wrigglesworth, director and general manager, Oldham and Sons Ltd., Denton, Manchester.

M.B.E.

J. A. Dunkley, development engineer and designer-in-charge, R. B. Pullin and Co., Ltd., Brentford, Middx.
H. Lloyd, chief experimental officer, Metallurgy Division, A.E.R.E., Harwell.
F. W. Townsend, experimental manufacturing manager, Plessey Co. Ltd., Ilford, Essex.

Appointments

Mr. Frank Taylor has relinquished the chairmanship of Taylor Woodrow Construction Ltd., in order to devote more time to the overall Group. **Mr. A. J. Hill,** now managing director, becomes chairman in addition. **Mr. T. Freakley** and **Mr. T. Reeves** become joint deputy managing directors, and **Mr. D. A. J. Ballinger, Mr. B. F. Higgs** and **Mr. H. R. MacDonald** have been appointed directors. Mr. Ballinger was agent in charge, then contracts manager, of the Calder Hall "A" and "B" atomic energy power station contracts. He is at present in charge of the company's nuclear energy department.

Mr. J. R. V. Dolphin, C.B.E., chief engineer to the Weapons Group of the U.K.A.E.A. since 1951, becomes chief engineer to A.E.R.E., Harwell, on August 1.

Mr. H. A. Lewis, M.B.E., T.D., B.Sc. (Eng.), A.C.G.I., M.I.E.E., A.M.I.I.A., director, as managing director of E.M.I. Sales and Service Ltd. He is also appointed commercial director of E.M.I. Electronics Ltd.

Rear-Admiral N. E. Dalton, C.B., O.B.E., as Engineer-in-Chief of the Fleet in succession to Vice-Admiral **Sir Frank T. Mason,** K.C.B., with effect from September 23; promoted Vice-Admiral on taking up the appointment.

Mr. John Montgomery as director, Shaw-Petrie Ltd. **Mr. Wallace Fairweather** as general sales manager of Clyde Tube Forgings Ltd., and Shaw-Petrie Ltd. He is located at the companies' London office at 157 Victoria Street.

Mr. Kenneth R. Pelly, M.C., succeeds **Sir Ronald Garrett** as chairman of Lloyd's Register of Shipping.

Major W. R. Brown, D.S.O., vice-chairman of The Power-Gas Corporation, as chairman and managing director, in succession to the late **Dr. N. E. Rambush.**

Following the acquisition of the Brush Group by the Hawker Siddeley Group, **Sir Ronald W. Matthews, Lord Cunliffe, Capt. R. C. Petter, Major N. E. Webster** and **Mr. Miles Beevar** have resigned from the Board of Brush. **Sir Frank Spriggs,** managing director of Hawker Siddeley, **Sir Roy Dobson, Mr. J. F. Robertson** and **Sir Arnold Hall,** members of the Hawker Board, have been appointed directors of the Brush Group.

Mr. L. Bennett as technical secretary of the Radio and Electronic Component Manufacturers Federation.

Mr. John F. Floberg, former assistant secretary of the U.S. Navy and now a Washington lawyer, and **Mr. John S. Graham,** former assistant secretary of the U.S. Treasury, and now a financial and business consultant in Washington, have been appointed members of the U.S.A.E.C.

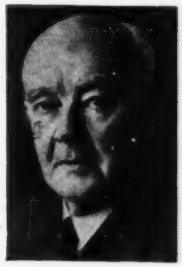
Mr. David W. Payn, T.D., F.C.C.S., as general manager and secretary to the Lead Development Association.

A. J. Hill.

D. A. J. Ballinger.

J. R. V. Dolphin.

H. A. Lewis.



Major W. R. Brown.

H. B. Topham.

F. R. Farmer.

Dr. Henri Polak.

Professor Luciano Cabala (left), Dean of the Faculty of Science, Concepcion University, Chile, speaks to Professor W. Murgatroyd, Head of the Nuclear Engineering Laboratory, Queen Mary College.

Appointments (contd.)

Mr. H. B. Topham as a director of the Anglo Great Lakes Corporation Ltd. The company was formed by four member companies of The Nuclear Power Plant Co. Ltd., in collaboration with the Great Lakes Carbon Corporation of New York to produce nuclear-grade graphite in a new factory near Stella North power station on the banks of the Tyne.

Mr. F. R. Farmer of the technical department, Design Office and Operations Branch, U.K.A.E.A., as chief safety officer of the newly formed Safety Branch of the Authority.

Dr. Henri Polak, recently scientific attaché for the Netherlands Embassy in Washington, D.C., and Ottawa, Canada, as European representative for Atomics International. He will be stationed in the North American Aviation offices recently established in Geneva, Switzerland.

Mr. L. F. Miller, principal assistant contracts officer, Central Electricity Authority, as deputy chief contracts officer at Headquarters.

Mr. S. H. Hughes, as sales manager, Electrical Measuring Division, Elliott Bros. (London), Ltd.

Mr. E. S. Waddington, F.S.E., M.Inst.W., A.M.S.A.I.Mech.E., as director of Grayonics Ltd.

Mr. S. G. Button as chief engineer, Electronics Division, Printed Circuits Ltd., an associate company of the Millett Levens Group.

Mr. H. O. S. Bridcutt, advertisement manager of *The Motor* has, in addition, been appointed deputy advertisement manager of Temple Press Limited.

Mr. C. E. R. Millidge, manager, Castrol division of C. C. Wakefield and Co. Ltd., and **Mr. A. A. Barr,** group publicity manager, as directors of the company.

Mr. F. Barrell, M.I.Mech.E., M.I.E.E., A.M.I.I.A., generation engineer (construction) in the Yorkshire division of the Central Electricity Authority, as generation construction engineer, C.E.A. Headquarters.

Mr. Kenneth Horne as director of Saben Hart and Partners Ltd. The organization is concerned with the design of nuclear equipment.

Mr. P. J. H. Coates, A.M.I.E.E., as director and general manager of Veritys Ltd.

Mr. J. H. Gameson, previously publications officer and editor, British Welding Research Association, as assistant publicity manager, Murex Welding Processes Ltd.

Awards

Professor Niels Bohr has been awarded the Ford Foundation's first " Atoms for Peace Award " of $75,000.

Dr. Lise Meitner (left), 79, the Austrian-born nuclear physicist, and Dr. Max von Laue, the German nuclear physicist, at the Free University in West Berlin after Dr. Meitner had been awarded an honorary degree by the Science Faculty.

H. S. Wingale, president, the International Nickel Company of Canada, Ltd., was awarded an honorary degree of Doctor of Laws at the annual convocation of the University of Manitoba on May 22.

Dr. Ugo Fano, chief of the Nuclear Physics Section of the National Bureau of Standards, has been awarded the Department of Commerce Gold Medal for Exceptional Service, in recognition of his " outstanding scientific accomplishment in the development of radiation theory."

Professor Otto Hahn, president of the Max-Planck-Gesellschaft, and **Sir Geoffrey Taylor** were made honorary Doctors of Science at Cambridge University on June 13.

Mr. G. Helps and **Mr. G. G. Farthing,** joint managing directors, were amongst the 35 members of the staff of Humphreys and Glasgow Ltd., who recently received gold watches to mark 25 year's service, or longer, with the company.

Tours

M. Francis Perrin, French High Commissioner of Atomic Energy, visited Poland early in June at the invitation of Polish officials interested in the peaceful use of atomic energy.

Mr. Koichi Uda, Minister in charge of Japanese atomic energy development, on a tour of inspection in Britain and other European countries, the United States and Canada.

Professor Luciano Cabala, Dean of the Faculty of Science, Concepcion University, Chile, spent two weeks in Britain during May. His purpose was to study the training of technicians for nuclear work, to visit research centres and manufacturers of research equipment.

Dr. Adenauer, West German Chancellor, conferred with **Mr. Lewis Strauss,** chairman, U.S.A.E.C. on the significance of scientific advances in peaceful and military uses of the atom during U.S.-German talks in Washington at the end of May.

Signor Enrico Mattei, chairman of Eni-Agip the Italian State-controlled oil corporation, arrived in the U.K. on June 14. It is understood that the corporation is seeking manufacturing licences to build British nuclear reactors in Italy.

Herr Kaun, general manager of the Stuttgart Public Utilities: **Professor Maguerre** of the Baden Electricity Works; **Herr Knelle** director of the electricity works "Schwaben" and a number of German technicians visited Britain at the end of May for talks in connection with the purchase of a Calder Hall-type of reactor.

Retirement

Mr. R. A. Bartlam, A.M.I.E.E., system operation liaison engineer, East Midlands of the Central Electricity Authority.

Obituaries

Nuclear Engineering records with regret the death of the following personalities:—

Sir Alfred Herbert, K.B.E., founder, chairman and managing director of Alfred Herbert Ltd., the machine-tool manufacturers. Sir Alfred was in his 91st year.

Professor Karl Friedrich Bonhoffer, head of the Max Planck Institute for Physical Chemistry, at the age of 58.

Orbits in Industry

THOSE of us not intimately connected with the electricity supply industry rather tend to take for granted that the advent of nuclear energy will only affect the method of producing the steam and that anything ahead of the turbine stop valve is "conventional plant," to use the standard term. If so, they should consult some of the papers read at the British Electrical Power Convention earlier this week, which indicate pretty clearly the repercussions to be expected as far afield as the transmission lines, although the two industries most affected are the manufacturers of boilers and turbines.

Both of these groups have been responsible for some spectacular advances in the past—as they will in the less familiar medium of the future. Paradoxically, however, the turbine manufacturers are faced with one problem that the boiler people are not; the future performance of "conventional" plant. No one would belittle the problems that face the boiler manufacturer; even though slag, sulphur trioxide, and fly ash have been eliminated from the gas stream. But he is not called upon to modify existing plant. Nobody expects a coal-fired boiler to be designed for ultimate operation with a reactor. Turbine designers, on the other hand, are not merely expected to produce tomorrow's sets with yesterday's steam conditions. They must also design big sets to be suitable for frequent starting and stopping, when nuclear stations carry all the base load, and today's base load sets are on two-shift working, in their old age. . . . Queen of the station today; "call girl" in 1975. It is a sobering thought.

Dropping the Pilot

"*Mijnheer de Voorzitter, Dames en Heren: Ik beschouw het als een grote eer gevraagd te zijn dit symposion over de Scaling-up van Chemische Installaties en Processen te openen . . . . . .*" It was a nice gesture on the part of Mr. E. LeQ. Herbert, managing director of the Shell Marketing and Refining Co. Ltd., to use Dutch for his opening address to the Joint Symposium on "The Scaling-up of Chemical Plant and Processes"; and must have made the many delegates from Holland feel that they were truly welcome.

This is the third joint conference held between chemical engineers of the two nations and, as Mr. Herbert pointed out, Church House, Westminster, was a most appropriate location: the engagement began five years ago as a mild flirtation and it was high time that the position was regularized.

Seriously, however, the value of a large conference on this subject can hardly be over-estimated. It needs much courage to attain what Mr. Herbert quoted as the ideal—to step straight from test-tube to full-scale production. Although the elimination of the pilot plant stage would usually save two years and a great deal of money, few are bold enough to undertake such a step, although one day, when we can extrapolate with more confidence, we shall.

Rigid Requirements

One outstanding example of the direct method can, of course, be found in our own industry. The chemical separation columns at Windscale, as recounted by Mr. B. F. Warner, whose paper is briefly summarized on p. 294 of this issue, were scaled up without employing a pilot plant because there simply was not time. This, in itself, would be handicap enough. The added requirement that no modification could be accepted, because of the heavy shielding, and that the design must be right first pop, must have made more than one of the team think wistfully of the infinite superiority of, say, tomato-growing as a career. Still, it came off, and added valuable information to the Symposium, which, as Sir Hugh Beaver pointed out, marks the first occasion when chemical engineers have regarded the subject as common ground, and not a collection of diverse problems for individual fields of chemical engineering.

X Certificate?

Most of us know by now that one should not toss large lumps of plutonium into a handbag, and that even solutions of enriched materials require special geometry for containing vessels. They may even have read the article on the prevention of unwanted criticality by Dr. A. H. Gillieson in the August, 1956, issue of this journal. Even so, the finer points of accidental criticality may still have escaped them. Recognizing this, the A.E.A. have made a film called "Criticality" which is intended to drive home to foremen and supervisors the unforeseen ways in which criticality could occur and the elaborate precautions which are, and must always be, taken to prevent such a possibility. Produced for the A.E.A. by Mr. Buckland Smith of the Film Producers' Guild, it seemed that only one thing was lacking—an introduction speaking the Ghost's lines from *Hamlet:*

> . . . I could a tale unfold whose lightest word
> Would harrow up thy soul, freeze thy young blood,
> Make thy two eyes, like stars, start from their spheres,
> Thy knotted and combined locks to part,
> And each particular hair to stand on end,
> Like quills upon the fretful porpentine. . . .

It was obviously impossible to allow actual criticality for the purposes of film making, but the animation effects carried out by Larkins Studio were sufficiently suggestive to fret any number of porpentines. For obvious reasons, it will not be shown to the general public, who will probably never learn to distinguish between a criticality excursion and the H bomb, but it should certainly produce results amongst those whose business it is to supervise the working of fissionable materials. In congratulating those responsible for their courageous action in producing this film one could almost take the words attributed to the Duke of Wellington . . . . "I don't know what effect they'll have on the enemy, but, by God, sir, they frighten me!"

Do-Yourself Kits

According to the *Daily Express* full sets of 75 drawings showing how to build an atomic reactor are on sale in the U.S. at $39.78 (uranium extra, one presumes). It won't be long before the Xmas toy trade is advertising . . .

> BOYS! Get your ATOM SCIENTIST'S KIT . . . white coat, overshoes, film badge, security card, canteen ear-plugs, miniature copy of *Nuclear Engineering*, half-finished bundle of manuscript, Admin. blue pencil, Ph.D. thesis, and rose-coloured glasses; all in strong cardboard box. . . . Also in stock, lead bricks, Bessel functions, strontium 90 . . . etc.

"Calder Herrin'"?

Victim of the latest intrusion of science into daily life is, apparently, the kipper. According to a report in *The Times*, the Herring Industry Board are considering the institution of a grading service (with inspectorate), whilst electrostatic smoke precipitation is already operating on a production basis.

In the bad old days, kipper quality was maintained by what is nowadays termed "consumer reaction." In other words, if kippers ceased to sell (or, in the more down-to-earth neighbourhoods were flung into the shopkeeper's face), he did something about it with his suppliers. The modern kipper, which so frequently resembles a brine-pickled pin-cushion, would have been automatically eliminated by the ancient principle of the survival of the fittest.

It is depressing to read, however, that Science is still unable to take out the bones—it would be uneconomic. Could not the A.E.R.E. come to their aid? Since irradiation is supposed to be particularly harmful to bone tissue, could not some form of selective bombardment be worked out to dissolve the bone? Or would it then necessitate a solvent extraction process to remove fission products? Maybe the whole problem is after all, really the province of the chemist—or, perhaps, the chemical engineer. Most of the shrunken specimens which now adorn (?) our breakfast tables could do with a scaling-up process, anyway.

Tangent

Industrial Notes

Manufacturing Agreements

Atomics International, a division of North American Aviation Inc. and Allmänna Svenska Electriska Aktiebolaget (ASEA) of Västerås, Sweden, have signed an agreement providing for technical assistance and co-operation in nuclear development. Atomics International have been responsible for two enriched-uranium projects under the U.S. experimental reactor programme.

ASEA has considerable experience in the manufacture of large generators together with transmission and distribution equipment. At present the company is designing a 75 MW reactor heating plant which will use heavy water as a coolant and moderator and natural uranium as a fuel.

Associated Electrical Industries Ltd. announce that from July 1, Siemens Bros. and Co. Ltd. and Edison Swan Electric Co. Ltd. will be merged into a single manufacturing organization to be known as Siemens Edison Swan, Ltd.

British Oxygen Co. Ltd. and **Ferranti Ltd.,** are working together on the computer control of flame-cutting machines. Using the Ferranti machine control system, facilities will include fully automatic profiling and edge preparation of plates for welding. The equipment, which will be demonstrated later this year, also provides for automatic control of the gas supplies to the cutting blowpipes, automatic ignition, pre-heat flame monitoring, nozzle-height sensing, and cutter-head rotation.

G. and J. Weir Ltd. have acquired a controlling interest in a Canadian engineering manufacturer and agent, Peacock Bros. Ltd., of Ville La Salle, P.Q.

Platt Bros. and Co. (Holdings) Ltd., have purchased a majority financial interest in Hayward Tyler and Co., Ltd. There will be no change in administrative policy or direction.

Hopkinsons Ltd., of Huddersfield, Yorks, have taken over manufacturing rights for Tansphere and Axiseal valves for the whole world except U.S.A., Canada and Germany. The Tansphere valve is designed for the control of large volumes of high-temperature gases.

Expansion

Marconi Instruments Ltd., are building a 22,000 sq. ft. extension to their factory at Longacres, St. Albans, Herts. The building will house a centralized engineering and development unit, including a drawing office and model shop.

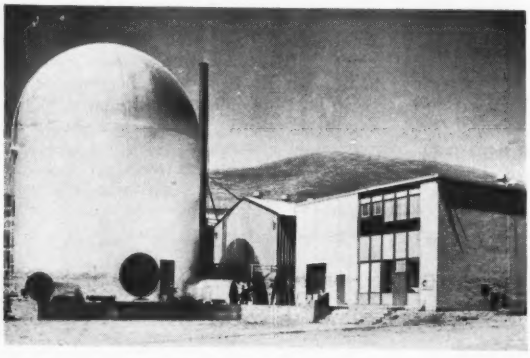
Hopkinsons Ltd., are erecting a new heavy machine and fitting shop for manufacturing large valves. The company has orders in hand for heat exchanger mountings and valves for Bradwell, Berkeley and the proposed Hunterston nuclear power stations.

Radio Heaters Ltd. have opened a new research laboratory at Wokington, Berkshire. The lab. will develop high-frequency induction and dielectric heating equipments of all kinds.

British Oxygen Gases Ltd., are building a new factory at Grangetown, Middlesbrough. It will produce compressed and liquid oxygen and liquid and tonnage oxygen. Estimated cost of the factory is £1¾ million.

Electrothermal Engineering Ltd. have extended their manufacturing facilities in the Southend area by a further 10,000 sq. ft.

General Electric of U.S.A. is to add a $4 million materials testing reactor to the $10 million Vallecitos laboratory recently dedicated at Pleasanton, California. Vallecitos facilities include laboratories for work on radioactive materials and experimental physics. G.E. are also erecting a 32,000 sq. ft. building at San Jose, for the fabrication of fuel elements.



General Electric's developmental boiling-water reactor at Vallecitos.

Contracts

BTH have been awarded a contract valued at £1 million to supply four 75 MW, 16 kV generator/motor units to Britain's first major pumped storage scheme at Blaenau Ffestiniog in North Wales.

Hayward Tyler and Co. Ltd., have received instructions to proceed with the manufacture of 176 glandless circulator pumps for Berkeley, Hunterston and Bradwell. The pumps—similar to those supplied for Calder "A" and "B"—will circulate hot water in the heat exchangers. The total cost is £430,000.

Blackburn (Dumbarton) Ltd., of Castle Road, Dumbarton, have received a subcontract for the manufacture of nuclear equipment from Matthew Hall and Co. Ltd.

Newalls Insulation Co. Ltd. have received a contract from Babcock and Wilcox for the thermal insulation of 16 stud-tube boilers with integral piping at Chapelcross nuclear power station.

Engineering Appliances Ltd., 106 Victoria Street, Westminster, London, S.W.1, are to supply bellows expansion joints for 5-ft. dia. main ducting for Berkeley and the proposed Hunterston power stations.

De Laval Steam Turbine Co., Trenton, New Jersey, U.S.A., awarded sub-contract to design and furnish the main rotating machinery and associated feed system auxiliaries for the nuclear-powered passenger-cargo ship which is to be built by Babcock and Wilcox Co.

Change of Address

Power Jacks Ltd. (hydraulic equipment) have moved from Valetta Road, Acton, to new premises at 353 Uxbridge Road, London, W.3 (Acorn 8692-3).

Acheson Colloids Ltd. Technical sales and service department now located at 70 Hill Street, Richmond, Surrey (Richmond 2066 and 2634).

Standard Telephones and Cables Ltd. New cable depot in Birmingham at 48 Kenyon Street.

Wharton Crane and Hoist Co. Ltd. London office now at Lincoln House, 296-302 High Holborn.

Blackman Export Co. Ltd. have moved from 23 Queen Square, London, W.C.1, to the head office of the parent company, Keith Blackman Ltd., at Mill Mead Road, London, N.17. The Queen Square address is now the London area sales office of the company.

British Industrial Truck Association is the new name for the Industrial Truck Manufacturers' Association, B.I.T.A.'s address is York Mansion, 94-98 Petty France, London, S.W.1.

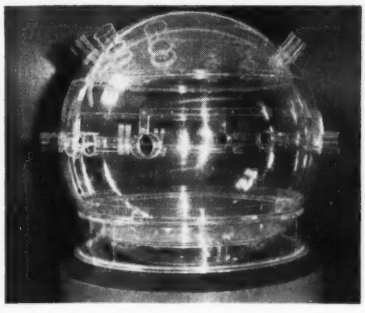
Correction

The upper photograph in an advertisement on page 33 of this issue is incorrectly described. The caption should read "Vacuum plant with controls for melting and casting processes."

Processes and Equipment

Flow Measurement

Coolant gas flow through the proposed Hunterston reactor is being studied by means of a 1/20-scale Perspex model constructed for the G.E.C. Simon-Carves Atomic Energy Group by Williaam J. Cox Ltd. The model comprises a sphere,



The 1/20 scale Perspex model of the G.E.C. Simon-Carves reactor for studying coolant gas flow.

3 ft 6 in. diameter with eight inlet and eight outlet ducts. Air drawn through the inlets on the lower section passes through the fuel channels and leaves the upper outlets. Flow readings can be taken at various points in the sphere. The model is not exactly to scale as certain modifications have been incorporated for manufacturing and experimental reasons.

(Williaam J. Cox Ltd., The Bothy, London Road, Tring, Herts.)

Freeze Grinding

When cooled to very low temperatures by liquid nitrogen (boiling point −195.8° C.), many substances acquire unusual properties. Rubber becomes hard enough to be machined. Zinc becomes brittle; so, to some extent, does carbon steel and iron; but aluminium, copper, brass and stainless steel are not affected by extreme cold. Based on these characteristics, a new technique, known as freeze grinding, has been developed. Freeze grinding is particularly suited to materials which are volatile or sensitive to heat or oxidation, including plastics like polyvinyl chloride where normal methods are slow and tend to produce particles rather ragged in appearance. Field trials in Britain, initiated by British Oxygen Research and Development, Ltd., have used stainless steel high-speed hammer-type mills fed by cooled particles from a heat exchanger to which the liquid nitrogen is fed from a small transporter by dry nitrogen gas cylinders. Most of the experimental work was carried out on polythene and nylon which are not easily powdered without generating enough heat to cause molecular degradation. The most promising results were obtained with nylon. Ignoring capital outlay, a cost analysis indicated that nylon could be processed for an increase of 12% on the raw material cost.

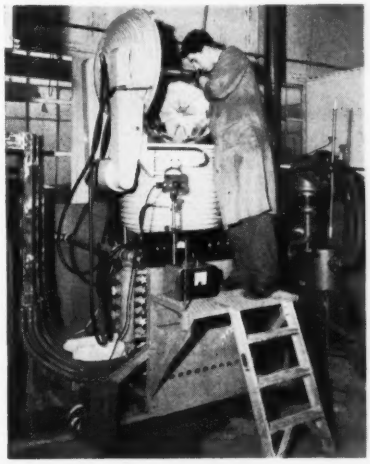
(British Oxygen Research and Development, Ltd., Deer Park Road, London, S.W.19.)

Heat Treatment

Graphite resistor furnaces capable of providing temperatures up to 3,000° C. have been developed by The G.E.C. They are primarily intended for development work at the high temperatures required in the heat treatment of the new metals—titanium, tantalum and zirconium; for sintering and also for brazing components which will operate at elevated temperatures.

One of the first of these new high-temperature furnaces has been installed in the B.S.A. Group Research Powder Metallurgy Laboratory at Small Heath, Birmingham. Designed to give temperatures up to about 2,000° C. and to maintain a good vacuum for the protection of a charge from oxidation, it is to be used for sintering materials for use at high temperatures.

The body of the furnace is a water-cooled, vertical, cylindrical steel tank with a hinged, domed lid. A vacuum-tight seal is formed between flanges on the lid and the furnace body. The charge is heated by radiation from a triangular-shaped assembly of graphite bars which surrounds the charge space. These graphite bars operate at a low voltage supplied by a three-phase transformer. A voltage regulator enables the secondary voltage of this transformer to be steplessly varied to give control over the heating rate.



Placing the top radiation screen of the new G.E.C. high temperature furnace in position.

Maximum rating of the furnace is 120 kVA. The furnace will take a charge approximately 9 in. diameter and 12 in. high with a maximum weight of 90 lb. With an alternate element arrangement the charge space can be increased to 11 in. diameter by 11 in. high. Provision is made to introduce a hydrogen atmosphere into the furnace chamber to hasten the later stages of cooling. The furnace and the charge are fully protected against failures in the electric and water supplies.

(General Electric Co., Ltd., Magnet House, Kingsway, London, W.C.2.)

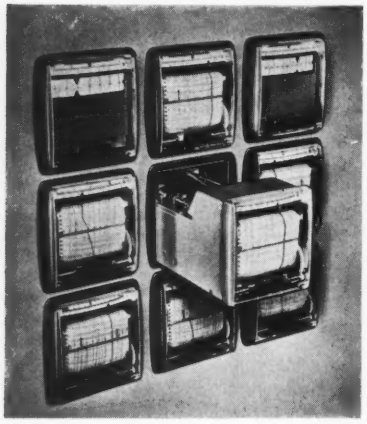
Air Dryers for Low Temperatures

After two years' rigorous testing, Lightfoot Refrigeration have introduced a unit type air dryer which will maintain high operating efficiency at temperatures down to, and below, freezing point. Eminently suitable for protecting electrical and mechanical equipment in unheated buildings, the units have a simple auto-defrosting device and can be arranged for either automatic or hand control. The machines incorporate a ¼-h.p. hermetically sealed refrigerating system; they are capable of removing up to 30 pints of water per day depending upon the relative humidity of the location.

(Lightfoot Refrigeration Co., Ltd., Abbeydale Road, North Circular Road, Wembley, Middlesex.)

New Consotrol Unit

A recent addition to the Foxboro-Yoxall range of Consotrol instruments is the M.54 recorder/controller. This unit is similar to the M.53 series except that it can be removed completely from the control panel when the transfer switch is in the "seal" position. All the external connections, electric and pneumatic, are of the plug-in type and when the unit is withdrawn from the panel a series of



The new M.54 Consotrol recorder/controller unit can be easily removed from the control panel.

air check valves automatically close to prevent loss of pressure in the impulse lines.

In common with other instruments in the Consotrol range the M.54 employs a full 4-in.-wide chart yet requires a panel face area of only 6 in. square.

(Foxboro-Yoxall Ltd., Lombard Road, Merton, London, S.W.19.)

Gaskets and Joints

A wide range of gaskets, joints, packings, shims and washers for all branches of industry is available from Wood Bros. and Co. (Gaskets) Ltd. In association with British Goetze Industrial Gaskets Ltd., the company's gaskets include metal joint rings, A.P.I. rings, serrated and bellows joint rings; spiral wound gaskets in stainless steel or monel with asbestos paper, C.A.F. or Teflon fillers; heat exchanger gaskets and joint rings in metal or C.A.F. or a combination of both; boiler cap gaskets and economizer joints. Materials used in manufacture include ferrous and non-ferrous metals, cork, rubber, asbestos fibre and plastics. The company is an approved supplier to the U.K.A.E.A.

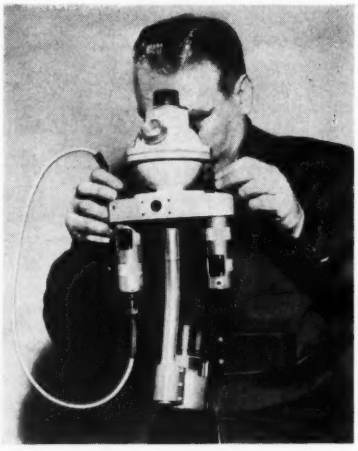
(Wood Bros. and Co. (Gaskets) Ltd., Dewsbury Road, Cleckheaton, Yorkshire.)

Ionisation Chamber

An uncompensated type of ionisation chamber has been devised by Atomics International. The chamber consists of a small cylinder containing two graphite electrodes—an inner graphite tube spaced about $\frac{1}{4}$ in. from the outer tube. Both are lined with boron-10 on their facing surfaces, making the chamber sensitive to thermal neutrons. The chamber is filled with dry nitrogen gas to provide a controlled atmosphere.

As neutron flux increases or decreases in the reactor, the ion density in the sensitive volume between the electrodes does likewise. An indicator connected to the chamber by wiring monitors information on neutron flux and reactor power. A lead case around the cylinder reduces gamma rays which might interfere with neutron detection. *(Atomics International, P.O. Box 309, Canoga Park, California, U.S.A.)*

Atomics International have developed this uncompensated ionisation chamber for measuring neutron flux.

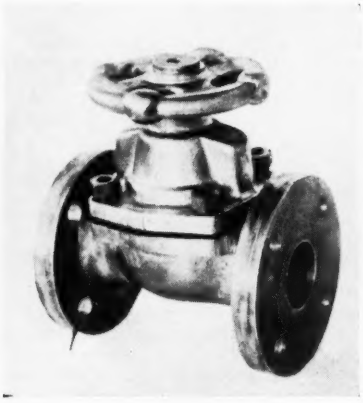


A lightweight magnetometer for the location of sub-surface magnetic materials is now being marketed by the Radiac Co. Inc. Used in the same way as a Geiger counter, the device is capable of delineating minerals of varying magnetic character. (Radiac Co. Inc., 489 Fifth Avenue, New York 17, U.S.A.).

Diaphragm Valves

Pearson-Scott diaphragm valves are designed to handle chemical, water, air, gas or oil services at pressures of up to 200 p.s.i. The body castings can be of iron or any suitable non-ferrous alloy, standard sizes ranging from $\frac{1}{4}$-in. bore up to 4 in., with either screwed or flanged connections.

The body and the diaphragm are the only parts of the valve that come into contact with the line fluid; the operating mechanism being totally enclosed and completely isolated. Recently the company have introduced a rubber-Fluon bonded diaphragm which offers long life without need for renewal. The Pearson-Scott valve could easily be arranged for controlling coolant gas flows in small-bore pipes in conjunction with a burst-slug detection system.



A typical Pearson-Scott diaphragm valve. Available with either flanged or screwed connections with iron or non-ferrous cast body.

(Scotts Engineering (Newport) Ltd., Stafford Road, Newport, Mon.)

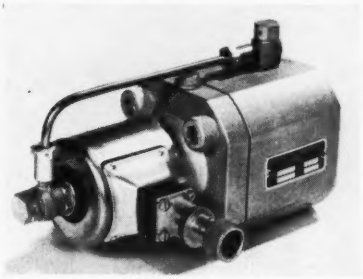
A range of flexible metal connectors comprising seamless-bronze or stainless-steel bellows brazed to flanged or screwed end fittings has just been introduced by Precision Heating Ltd., 142a Canbury Park Road, Kingston-on-Thames, Surrey.

Tubes and Fittings

For piping corrosive chemicals Talbot Stead Tube Co., Ltd., have introduced Melica tubing which has an outer covering of ferrous or non-ferrous metal with an inner lining of carbon. The standard range of sizes extends from $\frac{3}{8}$ in. bore to 4 in. in 6 ft lengths: special fittings secure continuity of carbon throughout the pipeline.

Talbot Stead are also marketing Forjend seamless stainless steel fittings—long radius standard weight elbows and return bends and standard weight equal tees, reducers and caps to B.S.1640 and American Standard ASA B16.9 with flanges to B.S.1560 and American Standard ASA B16.5.

These fittings are designed to cut the cost of pipe welding by speeding up the laying-out, lining-up and the actual process of welding. *(Talbot Stead Tube Co., Ltd., Green Lane, Walsall.)*



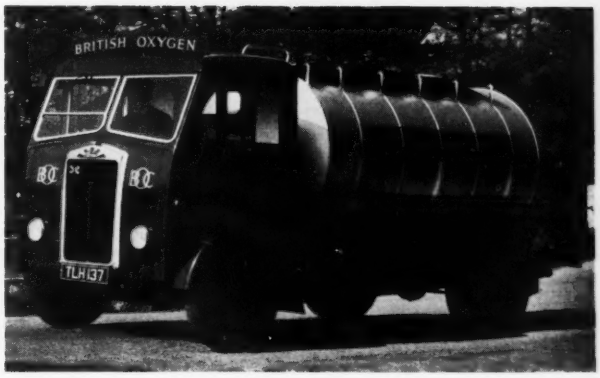
A new solenoid valve designed to handle large flows at very high pressures has been produced by Teddington Industrial Equipment Ltd., of Sunbury-on-Thames, Middlesex. This two-way piloted piston type of valve for the control of chemically inert fluids or gases up to 1650 p.s.i. can be made in sizes varying from ¾" to 2" bore. There are two main assemblies, a solenoid operated pilot valve and a piston type main valve unit. The valve can be arranged to open or close when energized.

Laboratory Balance

The Stanton single-pan Ultramatic is a new balance claimed to set new standards in speed and accuracy. The large pan space is easily accessible behind a sliding glass door; the dual release enables both hands to be used simultaneously for weighing; synthetic sapphire planes, with agate arrestment bearings are a standard feature. The entire instrument is enclosed in a strong, compact aluminium case. Width, 13½ in.; depth 16 in.; height, 21 in.; weight 32 lb. *(Stanton Instruments, Ltd., 119 Oxford St., London, W.1.)*

The new Ultramatic balance has a capacity of 200 grammes with a sensitivity of 1 mg. per division.

The familiar road tanker spheres used for carrying liquid oxygen may soon be replaced by cylindrical tanks. The prototype Albion Diesel tanker shown here has been developed in conjunction with British Oxygen. The 3- to 4-ton chassis is designed to carry 100,000 cu. ft of liquid oxygen.



In Brief . . .

Vitreosil electric immersion heaters for industrial applications can now be supplied with P.V.C. end-caps when required for heating acid electro-plating solutions, acid pickling banks and acidic chemical solutions. (The Thermal Syndicate, Ltd., P.O. Box 6, Wallsend, Northumberland.)

Sub-miniature, solid electrolyte 95V battery with projected shelf life of over 20 years, developed by General Electric of U.S.A. Designed for high voltage-to-volume requirements, this cylindrical axial-leaded battery is 31/32 in. long, .335 in. diameter and weighs .15 oz. (Speciality Electronic Components Dept., General Electric, West Genesee St., Auburn, New York.)

Equipment wire incorporating irradiated modified polythene dielectric for use in higher-than-normal temperature conditions has been introduced by Mersey Cable Works, Ltd., Linacre Lane, Bootle, Liverpool, 20.

Solder paint for speedy hot tinning of stainless steel developed by research laboratories of Perdeck Solder Products, Ltd., Waltham Abbey, Essex.

Educational Courses and Conferences

Nuclear Engineering—a week's residential course is being organized by Nottingham University with the object of providing an outline of the subject to engineers with little or no previous knowledge. The course begins on September 16. Applications should be made to T. L. O'Neill, hon secretary, University of Nottingham. Fee: £10 10s, plus residence, £7 7s.

Industrial Engineering—a one-year course at Loughborough College of Technology begins on September 17. Members must have had at least one year's industrial experience. Head of the Department of Industrial Engineering, Loughborough College of Technology, Loughborough.

Materia's for Nuclear Engineering.—A two-day conference—on July 11 and 12—has been arranged by The Physical Society (1 Lowther Gardens, Prince Consort Road, London, S.W.7). It will be held at the premises of Associated Electrical Industries Ltd., at Aldermaston, Berks.

Autoradiography is the subject of a five-day course which commences at the Isotope School, A.E.R.E., Harwell, on July 22. The course has been arranged in co-operation with Dr. S. R. Pelck of King's College, London. Fee: £10.

Industrial Carbon and Graphite is the subject of a conference, convened by the Society of Chemical Industry, which is to take place at the William Beveridge Hall, London University, on September 24, 25 and 26. Papers will be presented by specialists from Britain, France, Germany, U.S.A., Russia and other countries. Honorary secretary is Mr. E. A. Smith, Acheson Colloids Ltd., 18 Pall Mall, London, S.W.1.

Twelfth Electronics Course. A.E.R.E., Harwell, will hold a specialized course on the design, use and maintenance of electronic instruments used in nuclear physics, radiochemistry and in work with radioactive isotopes at the Reactor School from July 15 to 19. Application forms from Divisional Admin. Officer, Electronics Division, A.E.R.E., Harwell. Course fee: 25 guineas.

Plasma and Atomic Physics. A conference will be held at A.E.R.E., Harwell, on October 3 and 4. Subjects discussed will include atomic collisions, ionospheric physics and plasma physics. Intending contributors should write to Dr. P. A. Davenport, General Physics Division, A.E.R.E., Harwell.

Reactor Technology Training. The next courses for senior technical executives will be held at the Reactor School from October 21 to 31 and from January 6 to 16. Reactor School, A.E.R.E., Harwell. Fee: £50.

Reactor Safety. U.S.A.E.C., Atomic Industrial Forum and the American Nuclear Society will sponsor a conference in New York City on October 31. Atomic Industrial Forum, 3 East 54th Street, New York 22.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 769,292. Ion generating apparatus. P. P. Starling. To: U.K. Atomic Energy Authority.

All electrical leads and conduits entering the unit pass through vacuum tight seals which are demountable and remote from any source of heat.

B.P. 770,594. Use of nuclear fission in synthesizing organic compounds. To: Hercules Powder Co. (U.S.A.).

It was previously believed that only a fraction of beta, gamma, and neutron-radiation released from atomic fission was useful for chemical processing. Now it has been found that the effects from fissioning atomic nuclei may be used for initiating chemical reactions (particularly between organic compounds which are considered to be mutually non-reactive) by dispersing fissionable atomic nuclei throughout the reactants and causing fission. A fragmentation of the organic compound, or mixture of such compounds, will occur, and the molecular fragments so produced then combine to form new compounds different from the starting materials. For instance, atomic nuclei may be dispersed in an alcohol such as methanol. On fission, one of the carbon to hydrogen bonds in the methanol molecule is ruptured and the methylol fragments obtained combine to form ethylene glycol.

B.P. 770,649. Electrical control device. To: Pye Ltd.

Movement of a control member over an area of space (swinging in a universal joint) producing two electrical quantities relative to Cartesian co-ordinates, is usually biased along one or another of the two main axes. This is the result of friction in the bearings and in the electrical apparatus (potentiometers, resistances, etc.). This bias can be reduced to an insignificant amount by associating with the control member an isotropic friction device exerting a uniform frictional resistance (irrespective of the direction of movement) which is large compared with the other frictional forces. A spring-loaded friction element moving over a part-spherical friction surface is suggested.

B.P. 770,812. Method of lithium extraction. G. G. Collins, D. S. Taylor, P. J. O'Brien. To: Borax Consolidated, Ltd.

Extraction of lithium values from silicate ores (petalite, lepidolite, spodumene) by roasting at 450 to 700°C with the addition of reactants, one of which is preferably sodium nitrate or hydroxide; the other reactants being a carbonate, sulphate, oxide or hydroxide of an alkali metal (not lithium) or of an alkaline earth metal, followed by leaching with an aqueous medium.

B.P. 770,857. Gamma-ray detectors. To: Texaco Development Corp. (U.S.A.).

The conventional Geiger-Mueller counter can be made more efficient by filling with a mixture of the rare gases but there remains still the "dead time," i.e., the time interval during which the counter is insensitive after recording a count. The length of the dead time becomes very important where a high intensity of gamma rays is to be measured. A detector of the multi-cathode plate type (B.P. 612,899) is five to ten times more efficient than the conventional counter. Its dead time with a filling of a mixture of argon and anhydrous ammonia is about 100 microseconds. This time can be reduced as much as 50% by a filling of a mixture of argon (19.9 to 65%), helium (25 to 80%) and a small proportion of anhydrous ammonia (0.1 to 10%). The more helium is present, the shorter will be the dead time up to an optimum of 77% helium, 20% argon, and 3% anhydrous ammonia.

B.P. 771,111. Nuclear reactor. S. G. Bauer. To: U.K. Atomic Energy Authority.

In order to eliminate structural and sheath materials of large neutron-absorbing properties, the fissile material is disposed as extended films or layers sandwiched between pairs of plates of moderator material. The moderator envelope of the fissile material may be in the form of troughed or ribbed

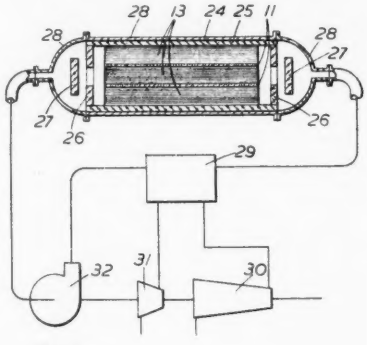


Fig. 1.

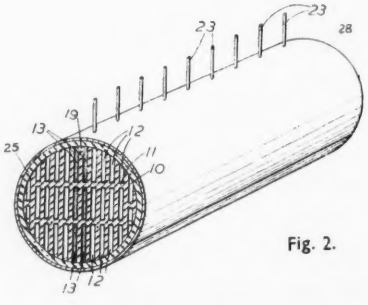
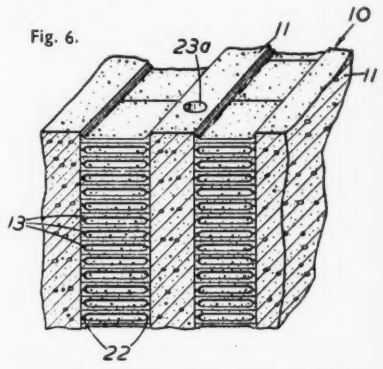


Fig. 2.

sheets to provide channels for coolant fluid between adjacent elements. Fissile material such as plutonium can easily be completely enclosed as a film or coating. When fertile material (thorium or natural uranium or an oxide thereof) is included, somewhat thicker layers may be necessary and the moderator plates will then be shaped or packed accordingly to contact each other along their peripheries. A reactor built up in this manner is shown in Figs. 1 and 2, a sandwich with shaped moderator plates in Fig. 6. 11 is the moderator frame of core 10 with channels 12 between sandwiches 13. Control members 23 extend through bores 23a into the core. The core is surrounded by an envelope of moderator and fertile material (graphite, thorium oxide) 25, 26, 27. The material in portion 25 acts as a partial reflector of neutrons. Envelope and core are arranged in pressure vessel 28 with an insulating layer 24 of carbon black. Coolant is circulated in a closed circuit containing also heat exchanger 29.

Fig. 6.



B.P. 771,222. High-voltage machines for the production of high-speed electrically-charged particles. To: Emil Haefely and Cie. A.G. (Switzerland).

The control of high voltages in ranges higher than 1 MV bristles with difficulties and at over 4 MV becomes nearly impossible. By accommodating the high-voltage generator in a pressure vessel filled with compressed gas, the size of the high-tension machine can be reduced. Repairs, however, of the generator remain difficult although they can

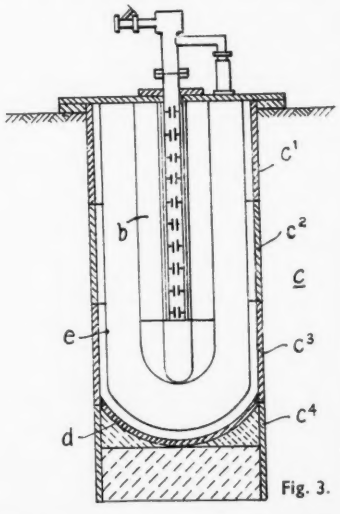


Fig. 3.

be facilitated by lowering the generator into the ground in such arrangement that the electrically charged particles are accelerated vertically so that they are then available in the laboratory above the generator. A simple and economical arrangement is shown in Fig. 3, the high-tension machine being shown at b. The pit is excavated with the aid of a cylindrical iron caisson (c), built up of ring sections c_1, c_2, c_3, c_4 welded together. The lower end is then closed with a dished, gastight welded bottom (d). The caisson vessel acting as counter-electrode would have to be carefully machined and polished inside. Alternatively, a thin metal screen may be suspended in the caisson.